APPLICATION OF LIM-IN-TRACK TECHNOLOGY AT AIRPORTS

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APPLICATION OF

LINEAR INDUCTION MOTOR IN-TRACK TECHNOLOGY

AT AIRPORTS

BY

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FOR

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Un sommaire en francais de ce document est inclus avant la table des matières.

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16. Abstract

A study of the application of Linear Induction Motor In-Track (LIT) systems at airports was carried out. The transport of air cargo, passengers and baggage both within and between terminals was examined and specific operating requirements were written. LIT systems for each of these four transportation modes were devised and defined to the stage of major hardware identification. An evaluation established that all four systems would meet the basic operating requirements at airports and therefore could be considered as potential system products for the airport market.

An examination was conducted to determine whether various systems could be combined so as to effect overall cost savings. Methods of combining the airport systems that were considered included:

- common track for vehicles;
- vehicles carried on larger vehicles in areas of joint routing;
- different guideways enclosed within the same guideway beams in elevated sections;
- dual gauge track on the same lane of guideway; and
- double track on the same lane of guideway.

The conclusion was that the combined system concepts considered were technically feasible and all had cost savings potential compared to the total cost for installing individual systems for each transportation mode.

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16. Résumé

Le présente recherche concerne la technologie du moteur linéaire à induction à voie active électrique appliquée aux transports aéroportuaries : transport du fret aérien, des passagers, de leurs bagages, tant à l'intérieur d'une même aérogare qu'entre deux aérogares ou plus. Elle a débouché sur la définition des exigences opérationnelles à satisfaire. Des études conceptuelles de systèmes utilisant ce type de moteur ont été élaborées à l'égard de ces quatre applications et les principaux composants à mettre en oeuvre ont été définis. L'évaluation faite a montré que les quatre concepts proposés satisfont aux exigences opérationnelles de base définies à l'égard des aéroports, au point de pouvoir être considérés comme susceptibles de pénétrer le marché des transports aéroportuaires.

La recherche a ensuite porté sur la possibilité de combiner les divers concepts de manière à minimiser le coût total. Les permutations envisagées ont été les suivantes:

- utilisation d'un même type de voie par tous les véhicules;
- transport des bacs à bagages à bord des véhicules de transport de fret aérien sur les tronçons communs du réseau;
- construction d'une structure fermée et surélevée à l'intérieur de laquelle circuleront deux voies ou plus;
- une voie à deux écartements et
- deux voies parallèles.

La recherche a montré que l'idée de combiner les divers systèmes envisagés est bonne et qu'elle est économique par rapport au coût total qu'entraînerait la réalisation d'un système séparé pour chacune des applications visées.

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Aéroport, moteur linéaire à induction à voie active électrique, transport, bagages, passagers, fret aérien	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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SUMMARY

This project examined the potential to apply Linear Induction Motor In-Track (LIT) technology to meet the operating requirements at airports for moving people, cargo, and baggage both within and between terminals.

The project objective was to establish the operating requirements and develop LIT transportation system concepts that would meet the requirements. As part of the analysis, UTDC considered alternatives for combining operating aspects of the systems to reduce costs and enhance economic viability.

The work performed consisted of two phases.

Phase 1 addressed the potential for LIT systems to solve specific problems at airports relating to the movement of:

- passengers;
- air cargo;
- baggage within a terminal; and
- baggage between terminals.

The methodology of this phase required the writing of operating requirements for each of the four transportation modes, the creation of a LIT system carried to the level of major hardware identification, and documentation of a model system configuration summary. An evaluation was then performed on each LIT system, leading to conclusions for this phase.

Phase 2 examined the opportunities for system cost reduction, and reduced guideway and facility requirement by combining various modes in some manner. The methodology selected was to assemble the subsystem experts together as a group, to perform both the "brainstorm", or creative part, and the evaluation or analytical part.

The early work leading to the operating requirement did clearly establish the interplay between airport design and transportation, especially as airports grow to require multi-terminal operation.

The work of the first phase was successful in two respects. Firstly, systems were devised for each mode. Whereas for passenger service and interterminal baggage, the systems can be basically developed with existing hardware, intraterminal baggage and air cargo required completely new hardware concepts. Secondly, the evaluation of each system provided a very positive result.

The evaluation of each of the four proposed systems was based on examination and assessment of the following considerations:

- Operating Requirement - Will the proposed LIT system meet the requirements specified earlier?

- o Automatic Operation - Will the system be fully automatic?
- o Route Feasibility - Can a system be installed at a typical airport?
- o Technical Risk - Is the system technically feasible?
- o System Cost - Does the system appear economically viable?
- o Alternative System Comparison - How does the LIT system features compare with potential or existing systems?
- o Mission Viability - Are the services or features offered really required?

On the basis of the study work, in general, for all four systems, the answers to these questions were positive and in no case negative. However in a number of areas, as indicated below, the answers are not conclusive, requiring work beyond the scope of this study.

Interterminal Baggage:

The LIT Baggage Transport System (BTS) is ideally suited to this requirement. Two issues are outstanding:

- o From the airport authority perspective, is the investment in system and guideway warranted for the service provided?

- o From the system developer's perspective is the investment in system engineering to optimize the system warranted?

Intraterminal Baggage:

The "low profile" LIT system devised is a very capable system, meeting the requirements identified in this study, capable of retrofit, and is competitive with existing systems at adequate route lengths.

The particular advantages of this system are its high transfer speed at longer distances, bag identification, and high reliability.

There are a number of issues which need to be addressed:

- o Certain technologies would require development which is not high risk from a feasibility perspective, but which would require very high reliabilities.
- o Is it practical to develop a "user friendly" client interface or is another approach required?
- o Are the perceived advantages of delivery of bags directly to the gates confirmed by the industry experts?
- o Are the demand requirements assumed confirmed in practice?

Cargo

The cargo LIT system devised in this study meets the operational requirements. The particular advantages are high speed and automatic operation. There are two key issues which need to be addressed:

- o The final link between the system and the aircraft needs further study, especially in the light of space constraints on the tarmac.

- Can the industry be organized to take advantage of the system, essentially by combining their operations in order to provide adequate system loading and use of off-site facilities?

Passenger

The LIT passenger system proposed appears ideally suited to airport application, and potentially offers more imaginative system layouts.

The key issues which need to be addressed are:

- Will an essentially conservative airport authority be open to a new technology and design so as to take advantage of its opportunities?

- Given the above, from the developer's perspective, is the additional investment in system development warranted in view of market size?

In general, these transportation systems offer a significant opportunity to design airports more optimally as an integrated system. To do so requires a strong overall airport operating concept and authority. In part, because of deregulation, the trend has been to divide the airport into independent units.

The work of the second phase was also successful. A number of concepts for combining systems were identified, and an evaluation found them to be generally workable, with resulting cost savings. It was clear that the concepts are not necessarily universally applicable, that is, at all sites, or even necessarily everywhere at one site. Nonetheless, it appears that in many instances, capital cost savings will result, as well as the obvious operating savings derived from the sharing of operating personnel and facilities.

One concept, for example, would consist of tracks, guideway, propulsion and control, and power distribution subsystems to be shared by the passenger, air cargo, interterminal baggage, and possibly intraterminal baggage systems.

A number of ideas were also generated in this work and were recorded for future follow-up. Among them was a proposal which would enable automation of virtually the entire baggage-handling operation, and enable simple detection of an individual's baggage on board the aircraft, a security feature.

The recommendations flow readily from the results of the work of each phase. Firstly, because each of these systems has merit on its own, it is worthwhile to address the technical or operational issues. Secondly, combination systems could provide the incentive to introduce these transport means at an airport, thereby solving some of the major problems which confront airport managers today. Thirdly, it is important for Transport Canada to evaluate the results and implications of this study in terms of

overall airport design, and the barriers to the introduction of new technology. The availability of these systems further enables a new approach to the design of airports, which cannot be neglected. Therefore, a study is recommended examining the applicability of combined systems at airports.

These recommendations require that the study be site specific, to ensure that realistic solutions emerge and to be able to "test" the concepts using the experience of field personnel.

SOMMAIRE

La présente recherche a porté sur les possibilitiés d'exploiter la technologie du moteur linéaire à induction à voie active électrique dans des applications aéroportuaires : transport de personnes, de fret et de bagages tant à l'intérieur d'une même aérogare qu'entre deux aérogares ou plus.

L'objectif de la recherche a été de définir les exigences opérationnelles, d'élaborer des concepts répondant à ces exigences et aussi d'envisager la possibilité de combiner les divers systèmes de transport dans le but de réduire les coûts d'exploitation et d'accroître la rentabilité.

Les travaux décrits se sont déroulés en deux phases.

La phase 1 a concerné l'applicabilité de chacun des concepts définis au transport :

- de passagers,
- de fret aérien,
- des bagages à l'intérieur d'une même aérogare,
- entre deux aérogares ou plus.

Pour cela, il a fallu définir les exigences opérationnelles à l'égard de chacune de ces quatre applications, identifier les principaux composants à mettre en oeuvre et esquisser brièvement la configuration à retenir dans chaque cas. Les configurations proposées ont fait l'objet d'une évaluation qui a débouché sur les conclusions qui s'imposent.

La phase 2 de la recherche a porté sur la possibilité de combiner les divers concepts de manière à minimiser le coût total par une compression des infrastructures nécessaires. La méthode utilisée dans ce but a été de réunir les spécialistes concernés et de les soumettre à des séances de "remue-méninges" créatrices et d'évaluation analytique.

Dès le début de l'étude des exigences opérationnelles, l'interdépendance entre la configuration de l'aéroport et celle des infrastructures de transport est apparue clairement, surtout dans le cas des aéroports obligés de construire une deuxième, voire une troisième, aérogare pour répondre à la demande.

La phase I a été couronnée de succès à deux ègards. D'abord des concepts ont été élaborés pour chacune des applications envisagées. (Alors que les systèmes étudiés pour le transport des passagers et le transport des bagages entre deux aérogares ou plus ne sont au fond que des variantes de systèmes existants, les systèmes de transport des bagages à l'intérieur d'une même aérogare et de transport du fret aérien font appel à l'innovation la plus totale.) Ensuite, l'évaluation des concepts en présence a donné des résultats positifs.

L'évaluation de chacun des concepts proposés a porté sur les points suivants :

- Exigences opérationnelles : le concept envisagé répond-il aux exigences définies?

- Automatisation : se prête-t-il à une automatisation poussée?

- Faisabilité opérationnelle : convient-il à un aéroport type?

- Faisabilité technique : est-il techniquement réalisable?

- Coût : est-il faisable sur le plan économique?

- Bilan comparatif : comment se compare-t-il à des systèmes existants ou à l'étude?

- Utilité : les possibilités ou caractéristiques qu'il offre répondent-elles à une nécessité?

Dans chaque cas, les réponses aux questions posées ont été généralement positives. Toutefois, sur un certain nombre de points, comme il apparaît ci-dessous, les réponses n'ont pas été concluantes, nécessitant de plus amples recherches sortant du cadre de la présente recherche.

Transport des bagages entre les aérogares

L'option étudiée convient parfaitement, mais il faut encore répondre aux deux questions suivantes :

- Du point de vue des autorités aéroportuaires, les investissements à consentir se justifient-ils au regard des services fournis?

- Du point de vue du promoteur, celà vaut-il la peine d'investir pour optimiser le système proposé?

Transport des bagages à l'intérieur d'une même aérogare

Le système à profil surbaissé (LP) conçu est très intéressant du fait qu'il répond aux exigences définies, que son emcombrement s'inscrit dans les limites dimensionnelles existantes et qu'il est compétitif sur des itinéraires de longueur adéquate.

Il a, en outre, les avantages particuliers d'une vitesse de transfert élevée sur de plus grandes distances, d'une aptitude à repérer les bagages et d'une haute fiabilité.

Mais il reste à approfondir certains aspects :

- Certaines technologies nécessitent des travaux de mise au point qui, tout en ne présentant pas des risques élevés su le plan de la faisabilité, doivent néanmoins garantir de très hauts degrés de fiabilité.

- Faut-il mettre au point une interface client-machine "conviviale" ou préférer plutôt une approche différente?

- Les avantages perçus de livraison des bagages directement aux portes d'embarquement sont-ils confirmés par les spécialistes?

- Les prévisions de la demande ont-elles été confirmées dans la pratique?

Fret aérien

Le système de transport aéroportuaire de fret aérien répond effectivement aux exigences, les principaux avantages étant la rapidité et l'automotisation. Deux aspects doivent encore être étudiés :

- L'interface entre le système et l'aéronef doit être approfondie, notamment à la lumière des constraintes imposées par le manque d'espace dans l'aire de trafic.

- Les transporteurs aériens sauront-ils s'organiser de manière à tirer tout le parti possible notamment des installations périphériques, pour une meilleure utilisation du système en place?

Transport de passagers

Le système de transport de personnes conçu semble convenir parfaitement à l'application définie, et se prête à des agencements novateurs.

Les aspects qu'il reste à élucider sont:

- Les autorités aéroportuaires connues pour leur conservatisme sont-elles prêtes à accueillir des nouveautés technologiques et à profiter des avantages qu'elles procurent?

- Compte tenu de ce qui précède et considérant la taille du marché, le promoteur est-il prêt à investir davantage dans la mise au point du système?

Généralement parlant, les concepts de transport aéroportuaire proposés peuvent constituer un apport très utile dans la réalisation d'aéroports mieux conçus parce que plus intégrés. Mais pour cela il faut une pensée directrice cohérente et globale, prenant le contre-pied de la tendance actuelle à la décentralisation découlant en partie de la déréglementation.

La phase 2 a, elle aussi, été couronnée de succès : elle a permis de dégager des idées intéressantes sur la manière de combiner les divers systèmes envisagés et l'évaluation des concepts proposés a été généralement favorable eu égard notamment aux économies rendues possibles. Il faut admettre cependant qu'ils ne sont pas nécessairement universels, c'est-à-dire applicables à tous les aéroports, ni même applicables partout dans un même aéroport. Néanmoins, ils permettent dans de nombreux cas de réaliser des économies, aussi bien au niveau des investissements à consentir qu'à celui des frais d'exploitation, ne serait-ce que par la mise en commun des ressources tant humaines que matérielles.

Une des idées mises de l'avant, par exemple, concerne la mise en commun des infrastructures et des systèmes de propulsion, de commande et de distribution de la puissance appelée entre les sous-systèmes de transport mis en oeuvre : transport de passagers, de fret aérien, de bagages entre plusieurs aérogares et peut-être aussi transfert des bagages conteneurisés.

La recherche a également débouché sur d'autres idées qu'il s'agira d'approfondir, notamment celle d'automatiser pratiquement toute la manutention des bagages, ce qui permettra de repérer les bagages d'un passager en particulier, déjà placés dans les soutes. Il s'agit là d'une mesure de sécurité intéressante.

Quant aux recommandations formulées, elles s'imposent de toute évidence à la lumière des résultats de chacune des deux phases. D'abord, étant donné les qualités intrinsèques de chacun des systèmes envisagés, il y a lieu d'en approfondir les aspects techniques ou opérationnels. Ensuite, la possibilité de combiner les divers sous-systèmes considérés pourrait amener les autorités aéroportuaires à les adopter, en vue de pallier certaines des grandes faiblesses qui caractérisent les transports aéroportuaires actuels. Enfin, il importe que Transports Canada analyse les résultats de la présente recherche et qu'il en évalue les conséquences sur la conception d'ensemble des aéroports et sur le plan des entraves à l'implantation des nouvelles technologies. Les systèmes proposés apportent un éclairage nouveau à la conception et au dimensionnement des aéroports, et constituent un atout à ne pas négliger. Une nouvelle recherche s'impose donc sur l'applicabilité de ces systèmes, adéquatement combinés, aux aéroports.

Cette recherche à caractère spécifique doit viser à trouver des solutions pratiques aux transports aéroportuaires et à les éprouver en faisant appel à l'expérience du personnel sur le terrain.

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GLOSSARY OF TERMS AND ACRONYMS

AGT	Automated Guided Transit: automated passenger carrying system such as the UTDC ALRT, Westinghouse and others.
AGV	Automated Guided Vehicles: popularly, unmanned, battery powered electric vehicles, rubber tired, which follow a wire embedded in a flat floor guideway.
BCCM	Block Communication and Control Module: a microprocessor based device used to exercise control over a particular section of track containing various active control elements. It will also communicate with devices (hardwire) and the central computer (multiplexed).
BTS	Baggage Transport System: a UTDC product designed to move baggage between terminals at an airport.
CAS	Collision Avoidance Scheme: a fixed block control approach to prevent collisions between cars, particularly between a normal and failed car.
IATA	International Air Transport Association
LCTS	Low Capacity Transit System: in this report generally referring to the ALCAN/UTDC vehicle which is part of the transit standard system.
LIM	Linear Induction Motor
LIT	Linear Motor in Track: a vehicle propulsion system in which the active portion of the linear motor (primary) is located in the track, and the passive portion of the linear motor (secondary) is located on the vehicle.
LP	Low Profile: the vehicle/system generated within this study to move baggage within terminals.
LSM	Linear Synchronous Motor
LVCM	LIM Voltage Control Module: a device for controlling linear motor thrust by varying the supply voltage. The device normally incorporates communication and sensor interfaces and control algorithms capable of vehicle control.
OR	Operating Requirement: a detailed and comprehensive document listing the performance required of a vehicle/system.
PDS	Power Distribution System
PIA	Lester B. Pearson International Airport

PMD	Permanent Magnet Decelerator: a device consisting of a linear array of permanent magnets with alternating poles. A vehicle passing overhead will experience a retarding force similar in nature to an "eddy current" brake.
RR	Reaction Rail: this is the secondary of the linear motor system, in this work, located on the vehicle. It normally consists of a backing of magnetic material, and a facing of conductive material.
SAE	Society of Automotive Engineers
SSS	Solid State Switch: a device for controlling a linear motor by turning it on or off.
STN CLR	Station Clear: a fixed block control policy in which the block is one station spacing. The trailing vehicle may be released when the lead vehicle has cleared its station.
STN ARR	Station Arrive: a fixed block control policy in which the vehicle in the station is fully protected thereby enabling release of the trailing vehicle out of its station when the lead vehicle has arrived in its station.
STN CLR+ STN ARR+	Plus: a modification to either control policy which creates additional control blocks by providing a fail-safe braking method between stations.
VVVF	Variable Voltage Variable Frequency: this term applies to a linear motor controller in which the thrust is controlled by varying supply frequency as well as voltage.

1.0 INTRODUCTION

1.1 BACKGROUND

UTDC has explored Linear Induction Motor In-Track (LIT) systems since 1982. Early work examined the EB Eddy "Sail Rail" air bearing technology with LIT propulsion as a very low capacity people mover. Subsequently, small linear motors and their control were examined in three separate programs. Much of this early effort was sponsored by TDC.

Subsequent to the "Sail Rail" study, UTDC with Ministry of Transportation of Ontario support, completed further develpment of people mover concepts. This included levitation and guidance research and wheel suspension analysis and evaluation. These projects resulted in the definition of a low capacity people mover system. UTDC then entered a joint venture with Alcan International to develop an Aluminum Structured Rail Vehicle, employing Alcan's proprietary aluminum bonding technology. This vehicle, developed for LIT propulsion, incorporated several other innovative design features. This vehicle is known as the low capacity transit system (LCTS) vehicle and is UTDC's in response to a market derived requirement.

Concurrent with the passenger development UTDC explored the application of LIT in materials handling. Proceeding through various stages of research, development and market definition, this line of inquiry culminated in a first generation LIT materials handling installation at Continental Can.

In 1987 Changi International Airport issued a Request for Proposal for an inter-terminal baggage transport system (BTS). Although the application was technically significantly different from the materials handling system being installed, it was felt that this was a unique opportunity and UTDC bid and won the contract.

1.2 AIRPORT FOCUS

While the Changi BTS certainly provided an airport focus, early passenger market examination had already identified airports as an important "people mover" market segment. UTDC performed various cost studies to evaluate, at least in a preliminary way, the LCTS concept at airports. While UTDC recognizes the airport market, several questions remain outstanding:

- The UTDC BTS system is a response to a technical specification, not an operational requirement. Does the BTS in fact meet the requirements for an inter-terminal baggage transport system?

- What are the requirements for moving baggage within terminals, and is the BTS suitable?

- Are there other applications at airports suitable for LIT, such as air cargo?

- If more than one system were installed at an airport, can significant economies be achieved by combining the systems in some manner?

1.3 STUDY PURPOSE

The purpose of the study, therefore, is to examine the potential to apply LIT technology to meet airport requirements with respect to moving people, baggage and freight.

2.0 ORGANIZATION OF REPORT

Figure 1 summarizes the report organization.

Section 6 reviews the market requirement, identifies and evaluates the LIT systems. This section responds to tne study purpose and therefore forms the main body of the reports.

This section is segmented into four parts, one for each of the systems i.e.,

- interterminal baggage
- intraterminal baggage
- passenger
- air cargo.

Each part will follow a common organizational structure.

1. Operations Review

   What is the overall function and purpose of the existing technologies/methodologies?

2. Role for LIT

   What portion of the overall function and purpose can be served by a LIT system?

3. Operating Requirement

   What are the specific requirements which the LIT system must meet?

4. LIT System Configuration Summary

   What does a LIT system fulfilling the requirements look like?

5. Evaluation

   How well does the LIT system meet the overall requirements of a product?

6. Conclusions

   What have we learned with respect to this application?

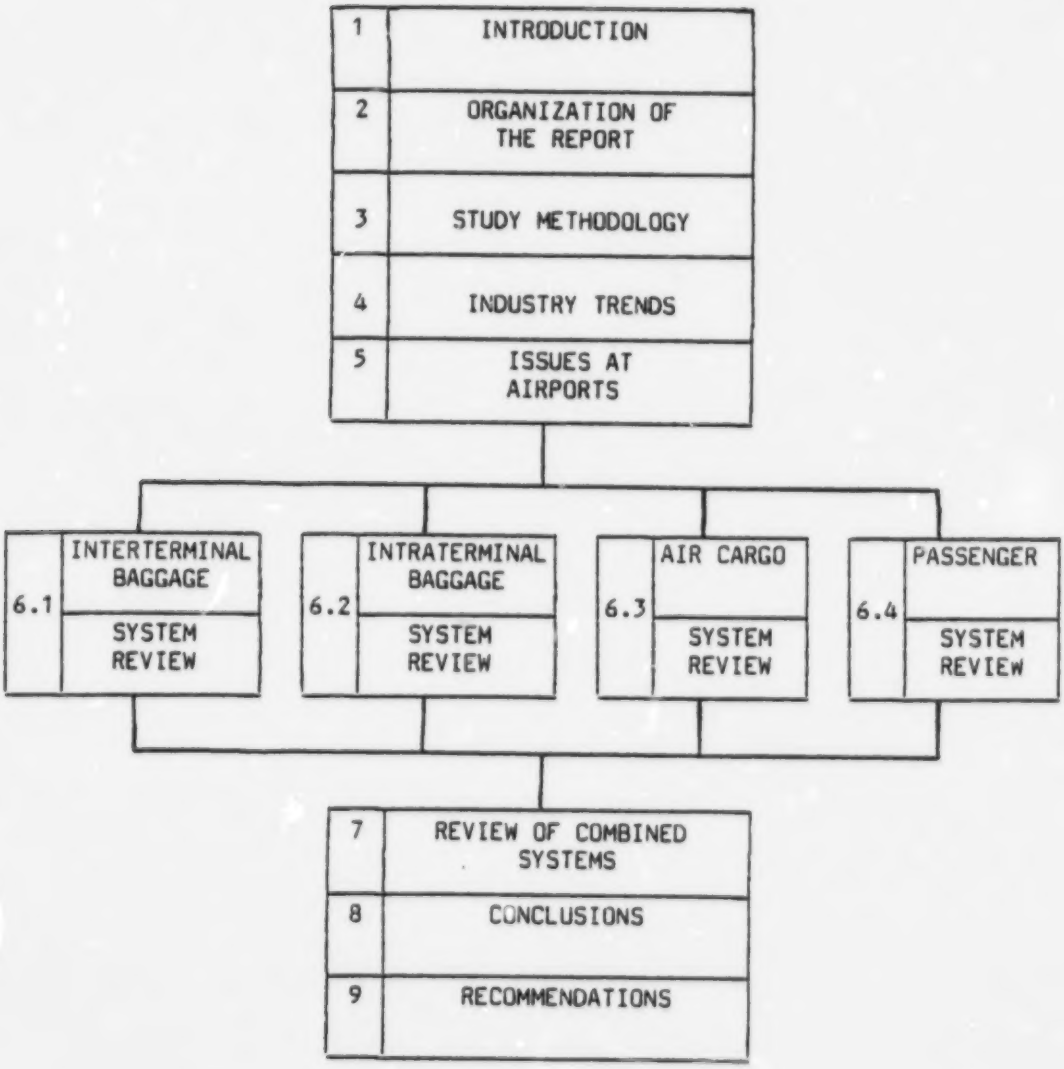


Figure 1: Report Organization

Therefore the main body of the report is Section 6, as shown below.

6.1	System Review
6.1.1	Operations Review
6.1.2	Role For LIT
6.1.3	Operating Requirement
6.1.4	Configuration Summary
6.1.5	Evaluation
6.1.6	Conclusions

The common elements of the report are covered in the preceding sections.

Items 1, 2 and 3 describe the study and the reporting of the results.

Items 4 and 5 present findings relating to the air transport industry in general, and the issues facing airports.

Section 7 is reserved for the review of combined systems, reporting on the specific methodology and results of the work.

Section 8 records the conclusions of the study as a whole.

Section 9 outlines the recommendations for the future based on the study as a whole.

3.0 STUDY METHODOLOGY

The work flow is shown in Figure 2.

The primary task was to identify LIT applications in passenger, baggage and freight. The methodology hinged on the premise that the systems derive from the needs and not vice-versa. Therefore the first four tasks were directed to the creation of four sets of operating requirements, independent, to the greatest extent possible of technology biases, whether LIT or existing technologies.

The second phase of the primary task was to identify LIT systems which might fill a role in the transport process and would meet the operating requirement. The intent was to provide system definition to the level required for evaluation. As an aid to this process a particular application was selected, intended to be representative of typical applications, and a configuration summary written.

The systems were then evaluated on the basis of a set of criteria, selected to address the relevant issues.

The secondary task was to assess the feasibility of combining various of the identified systems, so as to effect overall cost savings.

The methodology employed was to assemble the subsystem/system experts as a group. This was done to facilitate the creative "brainstorm" portion and also the subsequent evaluation portion.

While the project did anticipate that the activities of the primary task were interactive, the degree to which this was so was underestimated. This is because the writing of an operating requirement (OR) presumes a defined system boundary, and route structure presumes knowledge of the type of guideway, etc.

The methodology of the study was further based on a few key premises.

i) While the baggage and cargo investigation generate primary or first-hand data, the passenger investigation uses secondary data.

ii) While the study is general in its focus, on-site visits and interviews are the main tools of investigation, and because of its proximity Pearson International Airport becomes the primary site.

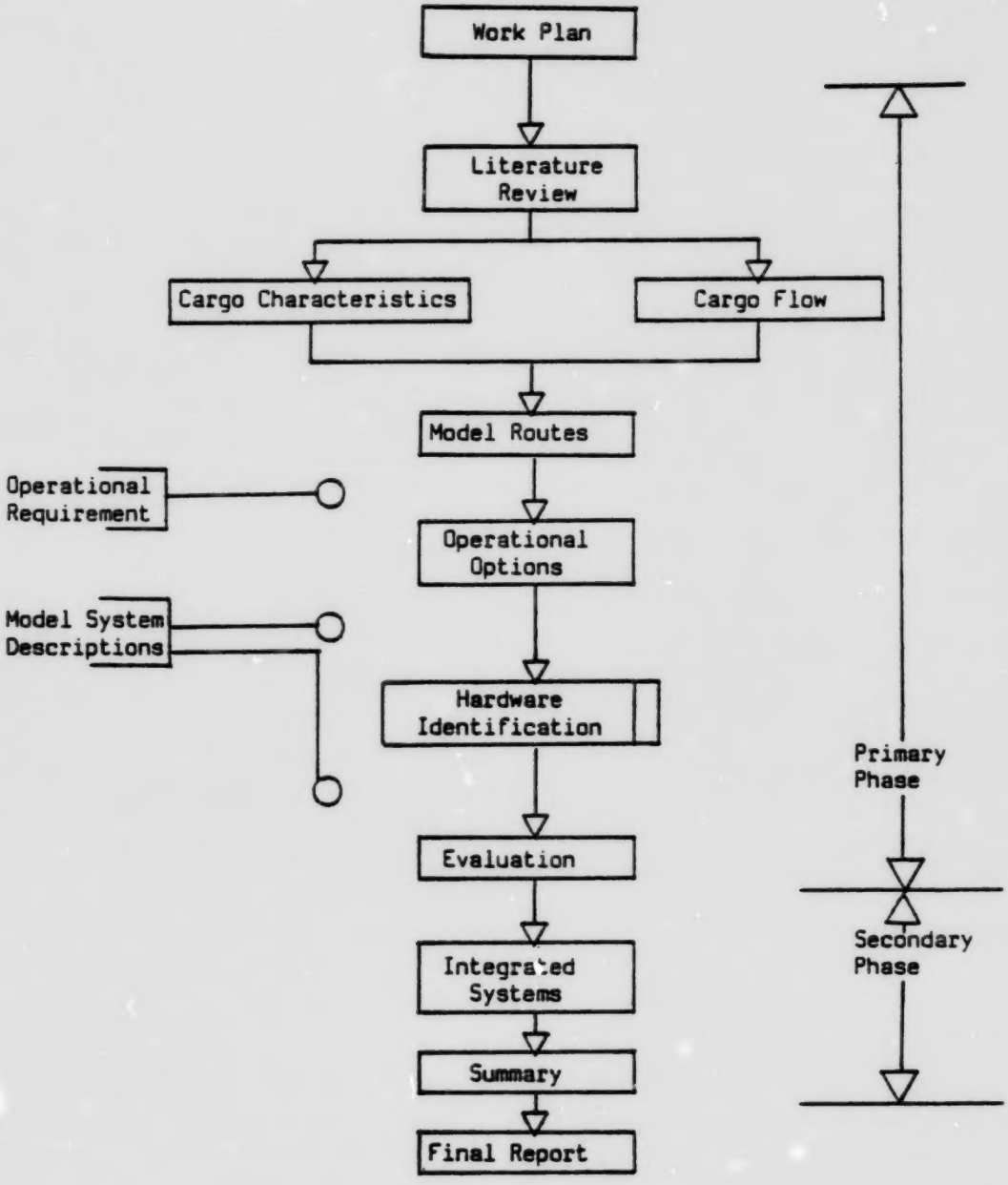


Figure 2: Project Work Flow

4.0 INDUSTRY DIRECTION AND TRENDS

4.1 MARKET SCENARIO

4.1.1 Passenger Market

Passenger airline traffic, although constrained during the recession period in the early 1980's, grew significantly in the period 1977-1986. During this timeframe, passenger traffic at major Canadian airports has increased 43% (refer to Table 1). Pearson International Airport, which handles over twice the passenger traffic of any other Canadian airport, increased passenger traffic by 58.8% during this time.

In the U.S., the Federal Aviation Administration expects the annual numbers of passengers using the nation's airports to increase greater than 70% in the period 1987-1996. It is also predicted that flights will increase at an average annual rate of 4.5% during this period. Forty percent of the 3,219 U.S. airports are already reporting capacity problems and it is stated that if air traffic growth continues at the expected level, the U.S. air transport system will be swamped. In a 1986 IATA report, "Summary of International Airport Developments", there are 115 major projects listed as in-progress or planned at airports throughout the world.

Because of the high passenger demand increase, there is a tremendous need to increase airport facilities to effectively handle the passenger flow. At many airports there are serious space constraints at curbsides, check-in stations, parking sites and airline gates. Also, baggage handling systems are becoming inadequate for the following reasons:

- the passenger volume increase;
- the use of widebody aircraft which means an influx of increased volumes of luggage for individual flights;
- the use of smaller aircraft to serve smaller markets also means an increased number of flights; and
- larger airports means longer and more complicated baggage systems.

The result is larger travel distances within the terminal area, which adds to the problem of getting passengers and baggage to and from the aircraft.

Enplaned & Deplaned Passengers (All Services) (000's)	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Preliminary 1987*
Edmonton Int.	1,627.7	1,805.7	2,198.8	2,438.1	2,399.1	2,132	1,952.9	1,991.6	2,001.1	2,055.4	1,928.1
Halifax	1,289.7	1,349.6	1,510.6	1,509.8	1,570.2	1,497.2	1,388.0	1,582.8	1,754.3	1,845.5	2,113.2
Dorval	5,386.1	5,584.9	6,162.3	6,304.3	6,219.4	5,438.0	5,143.1	5,610.6	5,545.5	5,676.7	5,969.3
Ottawa	1,611.1	1,715.2	1,882.2	1,949.9	1,969.7	1,886.1	1,877.1	2,106.0	2,272.5	2,262.5	2,443.3
L.B. Pearson	11,544.8	12,362.6	14,040.5	14,522.7	14,537.3	13,549.2	13,377.2	14,722.1	15,838.0	17,121.7	18,331.2
Winnipeg	1,964.8	2,032.4	2,275.3	2,413.6	2,375.1	2,085.3	2,004.8	2,117.4	2,150.6	2,267.4	2,228.0
Calgary	2,738.5	3,070.6	3,763.2	4,236.8	4,509.2	4,038.7	3,784.4	3,867.8	3,910.2	3,988.7	4,025.8
Vancouver	5,109.9	5,615.7	6,476.5	7,064.4	7,132.6	6,359.7	6,370.5	6,769.0	7,018.1	8,414.9	7,764.1
Mirabel	1,447.3	1,510.	1,551.2	1,407.3	1,244.8	1,213.5	1,278.2	1,466.9	1,716.4	1,850.3	1976.
Total	32,719.9	35,046.7	39,860.6	41,846.9	41,957.4	38,199.7	37,376.2	40,234.2	42,206.7	45,483.1	46,779.8

Table 1: Passenger Traffic at Major Canadian Airports

4.1.2 Cargo Market

Similar to the passenger traffic, the air cargo industry continues to grow at a rapid pace. The expansion of the small package/express parcel market has had a significant impact on the total air cargo market. In the 10 year period 1977-86, cargo traffic increased 29% at major Canadian airports (refer to Table 2). Pearson International airport, which handles more than 2.5 times the cargo volume of other Canadian airports, increased its volume 42%. In 1986 the Douglas Aircraft Company submitted a paper at an SAE Conference which forecast that air cargo development on a world wide basis would increase at an average rate of 6.6% to 1996. This is below the actual growth rate in the period 1977-86 which was 7.7%. The growth rate is based on revenue tonne kilometers. Customers in general, expect overnight delivery service and in fact much of existing (all cargo) freight is moved at night. This results in under-utilization of aircraft and personnel in many cases, and consequently air freight rates are higher than if freight moves were integrated to a greater extent with passenger traffic.

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Edmonton Int.	20.3	25.9	24.2	28.1	27.0	27.0	28.2	28.8	36.2	29.6
Halifax	12.1	12.4	13.6	12.5	16.1	14.6	14.6	18.5	19.0	18.6
PIA	154.5	164.6	180.9	178.5	175.8	179.1	189.7	220.2	230.4	219.2
Dorval	46.1	43.3	43.1	39.5	35.9	28.9	31.5	34.6	31.2	29.4
Mirabel	62.5	69.2	77.5	69.4	65.8	62.3	72.0	82.9	82.5	80.5
Ottawa	5.6	5.4	5.4	5.5	5.3	4.5	5.3	6.1	5.4	5.8
Vancouver	60.0	61.9	65.4	69.1	68.3	67.5	75.2	81.5	85.9	90.1
Winipeg	20.7	23.1	26.8	25.6	31.6	23.5	22.8	23.0	19.0	15.9
Calgary	18.1	19.5	23.6	23.3	26.3	27.8	30.0	35.1	32.5	26.7
Total	399.9	425.3	460.5	451.5	452.1	435.2	469.3	530.7	542.1	515.8

Table 2: Cargo Traffic at Major Canadian Airports

4.2 OPERATING SCENARIO

4.2.1 Airline Operations

The most significant development in airline operations has been the establishment of hub and spoke route networks. They are designed to consolidate flight operations at specific points (hubs) in such a way as to provide optimum traffic flow to and from low density, city pair markets. Similar networks existed prior to U.S. airline deregulation to some degree as one or more local airlines interlined traffic with one or more trunk airlines. However in post deregulation airlines have adopted competitive strategies that have fostered the growth of hub and spoke route systems, which conversely has reduced airline dependency on other carriers.

Hub and spoke operations generate the following benefits for airlines:

- increase airline revenues as passengers are retained on-line;
- creates more efficient use of aircraft and personnel; and
- generates higher average loads thereby allowing use of larger aircraft with lower unit costs.

Passenger benefits from this type of service are as follows:

- reduced inconvenience of aircraft transfer;
- higher quality of service; and
- reduced service problems, i.e., lost baggage.

In general, because of the increased competition between carriers, the airlines prefer to be as self-sufficient as possible, thereby providing as many services as possible without combining with competitors. This attitude, based on Transport Canada discussions, has contributed to decisions that led to the current plan for Terminal III, rather than progressing concepts for a remote terminal and centralized parking at Pearson International Airport.

5.0 ISSUES AT AIRPORTS

A review of the direction of and trends within the air transport industry identifies a number of areas that airport management is striving to resolve.

5.1.1 Landside Space

At many airports, the major concern stated is lack of landside space to accommodate the tremendous increase in capacity. Curbside space is often noted as the most serious aspect of this problem.

As a result there are a number of cities that are evaluating the feasibility of providing transit access from major city locations to the airport, similar to the transit services provided at London and Chicago. It is reported that Toronto, Rome, Geneva, Singapore and Jakarta are presently seriously evaluating concepts and proposals.

5.1.2 Airport Development

Although the increased traffic volume warrants new major airport development, due to various reasons such as restricted space, commercial opposition, etc., many cities are trying to make do with current facilities. As a result, serious consideration is being given to installation of new systems at existing terminals that will increase processing productivity and therefore adequately handle the increased volumes that have occurred in recent years. This includes systems that can more effectively handle passengers and cargo as well as visitors and employees.

5.1.3 Airport Security

Increased security at airports has become of crucial importance in recent years and will be a prime concern in the foreseeable future. The ICAO has ruled that for security, the passenger and his baggage must be matched before departure. At present, baggage handling operators must board aircraft and hunt through containers and free stored baggage until the bags for the unboarded passenger are found. It is expected that more automated systems will be developed to expedite this processing requirement. Another concept expressed in the articles that have been reviewed is a card system which authorizes the holder to proceed to gate areas.

5.1.4 Industry Labour Costs

It is stated that one of the few remaining areas in which airlines can reduce costs is labour. It is forecast that airlines can be expected to give more work to the passengers. The self-ticketing

features of airline shuttle operations is an example. One concept includes fully automating the ticketing/boarding process. In this system, the passenger would pass his ticket card through a sensor which would then allow access through a turnstile to board the aircraft. The operating procedure would be similar to that used for subway transit systems.

5.1.5 Cargo Handling

For cargo handling, there is a trend to more fully utilize passenger aircraft storage space for movement of cargo. The Douglas Aircraft Company, in their 1986 paper at the SAE conference, predicted that 58% of the revenue tonne kilometers in the year 2000 would be generated by passenger aircraft. It is recognized that this may require that customers accept second day delivery versus overnight delivery, but that lower air freight rates will gain acceptance of the schedule delay. A Douglas Aircraft company study at a major hub terminal identified that during peak periods, cargo and baggage containers had to be removed from up to 30 aircraft, sorted, and rerouted for loading on up to another 30 aircraft all within a one hour period. This identifies that automated cargo handling systems that will effectively locate containers for flights will be of prime consideration in the future.

5.2 DISCUSSION

The character of an airport is determined by the requirements of the aircraft. The impact derives from the requirement to take-off and land, and to park.

To safely handle typical modern era passenger aircraft there is a requirement for at least two runways, each approximately 3,000m in length. They must be roughly at right angles to each other and essentially non-intersecting. Therefore, the area of an airport will typically be in excess of 1,000 ha.

The reason land is at a premium relates primarily to transportation issues; providing access to, from and between facilities and the need to group facilities on one side of an airport. At PIA, for example, the passenger terminal facilities occupy only a small portion of the total land area, even including the extensive and complex road access system.

The acceptance of transportation systems for baggage, freight and people can play a major role in airport configuration and design.

The linear scope of a passenger gate is determined by aircraft size and aircraft turnaround time, and schedules determine gate

utilization. With increasing operations, terminal size increases. Terminal II at PIA is about 950 metres long and imposes significant walking demands on the passengers. The trend is to add new terminals as airport capacity increases. The key capacity measure is the number of emplaning/deplaning passengers. We can use the terminal II at PIA as an example of the basic relationship between gate space and terminal capacity.

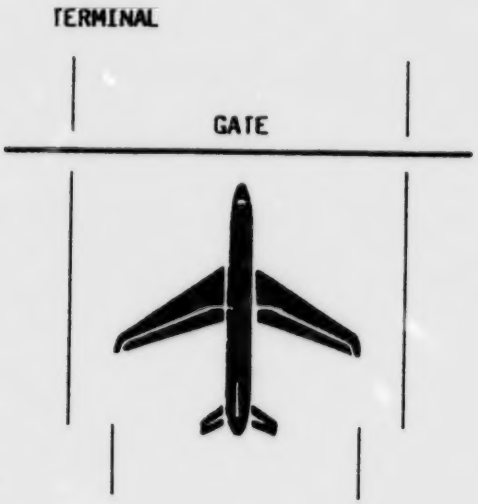


Figure 3: Gate Configuration

Sample Calculation

5.2 pass/m average mix of aircraft
950 m T-II length
1250 peak hour/annual rate (1)
1 hr. aircraft turnaround time (assumption)
.80 space utilization factor (assumption)

annual passengers = $5.2 \times .8 \times 950 \times 2 \times 1250$

$= 9.88 \times 10^6$

Terminal II as at 1988 handles 11 million passengers annually.

(1) "Baggage handling systems" R.H. Bode.

Therefore, as airport capacity grows, new gate space must be added, and new terminals must be added, either contiguously or separately. It is usually preferable to provide a stand-alone facility in order to deal with access, parking etc. However, this decision is largely an issue of transportation.

The nature of the transportation demand at an airport depends on its nature and layout.

There are two measures of airport capacity relating to people. They are as follows:

E/D Emplaning/Deplaning passengers - these are the passengers who enter or leave the airport from the air side; and

O/D Origin/Destination passengers - these are the passengers who enter or leave the airport from the ground side.

The difference between these categories may be termed the "transfer" passengers.

In general, the origin/destination passenger load relates to the population base in the area, adjusting for socio-economic factors, alternative transportation facilities and the relationship to potential destinations.

The emplaning/deplaning passenger load relates to the origin/destination passenger load and the extent to which the airport serves as a hub in a hub and spoke system.

Of course both are related to the proximity of alternative airports.

For example, none of LaGuardia, JFK and Newark are in the top ten busiest airports (in terms of operations) in the US partly because the three airports share the cachement area, and partly because none is a key hub.

On the other hand Atlanta and Chicago are the two busiest airports, primarily because they are transfer points.

It is important to differentiate between the two categories of passenger because of the impact on ground transportation demand.

Origin/Destination passengers use the parking and ground transportation facilities because they tend to use one terminal only.

A large percentage of the transfer passengers place no load on the transportation facilities because they use one terminal only.

However, it is the remaining transfer passengers who provide the major demand for interterminal travel. PIA can be used as an example. Data and projections for 1986 were based on reference (2).

(2) "TTA Intra-Airport Transportation Study" August 1980 Transport Canada

Emplaning/Deplaning Passengers:	17,121,700
Origin/Destination Passengers	12,609,500
	4,512,200

	Peak Hour Demand	Annual Pass.	Ratio
Connecting passengers	406	4,512,200	90×10^{-6}
Origination/Termination	322	12,609,500	26×10^{-6}

Table 3: Interterminal Transit Demand

Therefore it is seen that the transfer passenger places much more demand on interterminal travel.

The difference between origin/destination passengers and transfer passengers applies to baggage as well as passengers. To a large extent, transfer baggage is sorted at the origination point and some is in a form enabling direct transfer, aircraft to aircraft. In general however, the transfer passenger baggage must be handled, even if it is to the same terminal.

It can be seen that airport configuration and design will be greatly influenced by the availability of transportation. Alternatively, the present trend to design terminals as stand-alone facilities may be the result of the non-availability of suitable transportation systems.

The important criteria for transportation systems at airports are:

i) adequate capacity;
ii) cost effectiveness at capacity;
iii) system reliability/availability;
iv) level of service;
v) adequate speed; and
vi) ability to cope with the operating environment.

A brief examination of how well conventional systems meet passenger requirements shows that system cost at the low system capacities required is too high, the level of service is too low, although in general, the level of reliability is adequate.

5.3 THE ROLE FOR LIT SYSTEMS

The LIT systems are in some respects very different from conventional systems. In providing responses to the operational requirements, it is important to review some of the unique aspects of LIT systems. Most of the advantages benefit passenger, air cargo and baggage transportation equally.

- Because the propulsion system is largely offboard, vehicle height can be significantly reduced. Therefore the vehicle cross-section is reduced, lowering guideway costs for tunnels and covered elevated guideways. Further, platform height can be reduced.

- With the vehicle propulsion system largely off-board, the mass per unit length of train is reduced, thereby reducing elevated guideway costs in certain circumstances.

- With the propulsion system offboard, reducing vehicle size carries a lower cost penalty, thereby offering better service levels at lower system capacity.

- As a system, greater inherent redundancy within the propulsion and control system results in very high mission reliability and availability or adequate reliability with a large number of trains.

- Tractive effort independent of adhesion offers reliable operation in all weather, and the ability to cope with grades.

- The wayside based propulsion and control system results in a simpler vehicle with improved vehicle reliability, thereby increasing system reliability.

- In general, the propulsion is non-wear compared with on-board, has fewer failure points and permits propulsion components to be located off-board in a relatively vibration free environment.

- With LIT, the systems have in place the elements for automatic operation, and are easily made automatic.

5.4 CONCLUSION

Returning to the opening statement of issues of this section, it can be seen that LIT system attributes do address these major issues.

- Landside Space

  An efficient transportation system enables offsite facilities, such as parking lots, processing centers and linkages to other transport. For example, a connection to a public transportation facility reduces the loading at all terminals.

- Airport Development

  Links between terminals helps to load level demand for parking, for example. Efficient transport offers the prospect of infield development connected via a tunnel.

- Airport Security/Labour Costs

  The attributes of automatic operation and an inherent ability to "sort" lend themselves to application for improved productivity and control.

- Cargo Handling

  The potential exists to provide efficient transport.

The task undertaken in this study was to examine requirements and devise LIT systems which might provide some or all of the potential benefits.

6.0 SYSTEM REVIEW

6.1 SYSTEM REVIEW - INTERTERMINAL BAGGAGE

6.1.1 Operations Review

The general review of baggage handling is presented in Section 6.2.1. Interterminal baggage represents a small proportion of total baggage, but a very critical portion in terms of complexity.

In practice, interterminal baggage is "inter-line" baggage as seen in Figure 7 of Section 6.2.1. It is the baggage coming off the plane destined for other airlines. When the airlines are in another terminal then it becomes interterminal baggage. This baggage can be transferred by taking the carts, containers via dollies to the other terminal(s) or it can be taken to the arriving terminal and sent via an interterminal baggage transport system.

Therefore, one role of the interterminal system is to take the undifferentiated bag from one terminal to another, where there may be more than one destination.

Alternatively, baggage can be differentiated by flight and after interterminal, transport integrated into the intraterminal system. This would effectively eliminate one sort.

6.1.2 The Role for LIT

An LIT system is fully capable of performing the major function identified which is the transport of baggage between one or more terminals.

6.1.3 Summary of Operating Requirements

The following requirements are extracted from Ref. 1

- Line Capacity

  975 bags per hour per direction

- Trip Time/Speed

  maximum 10 minutes
  speed 25 kph

- Acceleration/Deceleration

  no practical limits

- o Grade Capability

  $\geq 30°$

- o Curving

  radius $\leq$ 1.5 m

- o Load Size

  no bag $>$ .91 m x .74 m x .38 m

- o Load Mass

  no bag $>$ 34 kg

- o Environment

  between terminal operation

- o Mean Time To Restore or Back up (MTTR)

  $\leq$ 5 min

- o Availability

  no critical provided MTTR is met.

6.1.4 Configuration Summary

6.1.4.1 Introduction

The vehicle size is dictated by the specification. However, at 9 bags per vehicle and an overload case of 3 vehicles/min, the nominal system capacity is 1080 bags per hour per direction. Because of the protected environment and masses involved it was feasible to use polyurethane wheels. This selection tends to reduce noise, improve manoueverability and allow the use of a standard I-beam as track.

Because the cargo is not human, a number of features are enabled:

- o "sling-shot" propulsion, i.e., LIM spacing greater than vehicle length
- o jerk control is not required
- o high accelerations are feasible *
- o curves at speed are feasible *
- o short vertical transitions are feasible *

- o non-damaging collisions can be part of the operational strategy
- o damaging collisions can be accepted, based on economic and operational factors only
- o vertical grades are limited by propulsion only.

Because of the protected right-of-way, high speeds are enabled, and a maximum of 11.4 ms^{-1} was selected.

The system uses manual loading, but automatic unloading is provided. System operation is fully automated with selection of destination provided at the manual loading station.

- * maximum lateral, longitudinal and vertical accelerations are approximately 1 g.

6.1.4.2 Model Route

See Figure 4 for the example route. The route is typical of airport industry applications.

The total track length is 2,500 m. The entrances and exits from the tunnel to the functional areas and the Maintenance and Service Area are characterized by elevation changes of 6.34 m and slopes of 30°. Further elevation changes in the functional areas of approximately 3.2 m permit access to the load and unload stations.

The unloading stations are manual and automatic, and the loading stations are manual. The maintenance and storage centre is elevated with respect to the tunnel and provides an operational buffer for full and empty cars.

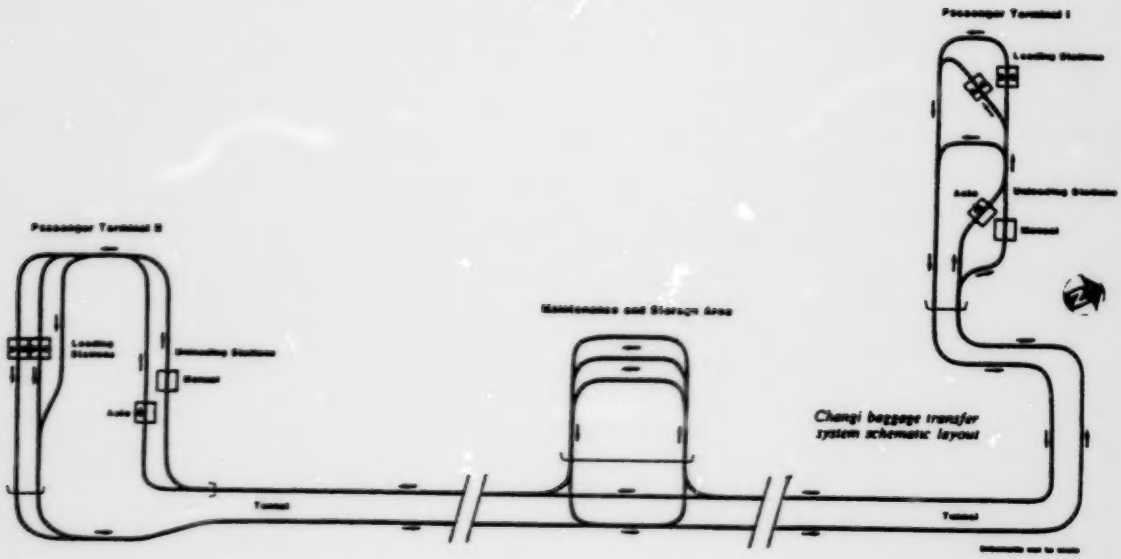


Figure 4: Interterminal Baggage Handler - Changi BTS

6.1.4.3 Capacity

A maximum continuous throughput of 2 cars/min (1080 bags per hour per direction) is required. The maximum interterminal one way travel time is 240 seconds and the estimated round trip time is 600 seconds or less. The automatic unload time is 20 seconds, and the manual unload time is 60 seconds. The system is designed for a 50% overload, and higher transitional dispatch rates.

6.1.4.4 Speed

The vehicle operating speeds for this example are 9 m/s in the tunnel and 4.5 m/s and lower in functional areas.

Note that for a given LIM, the operating speed is proportional to the supply frequency. A 50 Hz supply is used in this system, therefore the velocities are lower than in a 60 Hz system.

Curving requirements are 9 m/s on 8 m radius curves and 4.5 m/s on 3 m radius curves.

6.1.4.5 Control Philosophy

All real time control functions are performed locally. System supervision is performed by a central computer.

The collision avoidance scheme for the Changi BTS is based on the "fixed block" protection principle.

The overall track layout is divided into blocks. No vehicle can enter a block if such block is already occupied by another vehicle. The length of the blocks determines operational headway. In the tunnel, where vehicles are widely separated, the block length is 60 to 75 m. In the functional areas, including the section of track passing the storage and maintenance area (SMA), block boundaries are strategically located and always at the top of ramps where applicable.

6.1.4.6 Vehicle

Figure 5 illustrates the Changi BTS vehicle. Figure 6 shows the vehicle envelope. The vehicle was designed to carry ten bags for a payload of 136 kg and a nominal gross mass of 366 kg.

6.1.4.7 Guideway

The system consists of at-grade, elevated and tunnel sections. The interterminal link is in a cut and cover tunnel while the at-grade and elevated sections are in the terminals. On the

at-grade and tunnel sections the running rails are fastened to the concrete through tie plates and anchor bolts, while the LIMs are fastened to the concrete through mounting brackets along the centre line of the track. In the elevated sections the running rails are supported on portal frames having the same I-section for columns and cross beams as the running rail. The LIMs in these areas are mounted to angle or channel steel sections which are supported from the underside of the running rails by way of welded connections.

Clearance requirements inside terminals sometimes create unique problems for the guideway designer. In such circumstances, if larger spans lead to unacceptably deep guideway cross sections then the track may be suspended from the terminal ceiling. The possibility of such imposed load conditions on the ceiling as well as terminal floors should be allowed for at the design stage of new terminal buildings.

6.1.4.8 Track and Switches

The primary track element is a simple I-beam, which provides the horizontal surfaces for the carrying wheels and the vertical surfaces for the guide wheels. Positive roll-over protection is provided in this configuration. These symmetrical sections can be readily rolled to provide horizontal and vertical curvature.

Switching is fully wayside based, simplifying the vehicle, the guidwheels running in a slot in the track. Actuation is based on a necessity action principle, failing to a safe condition.

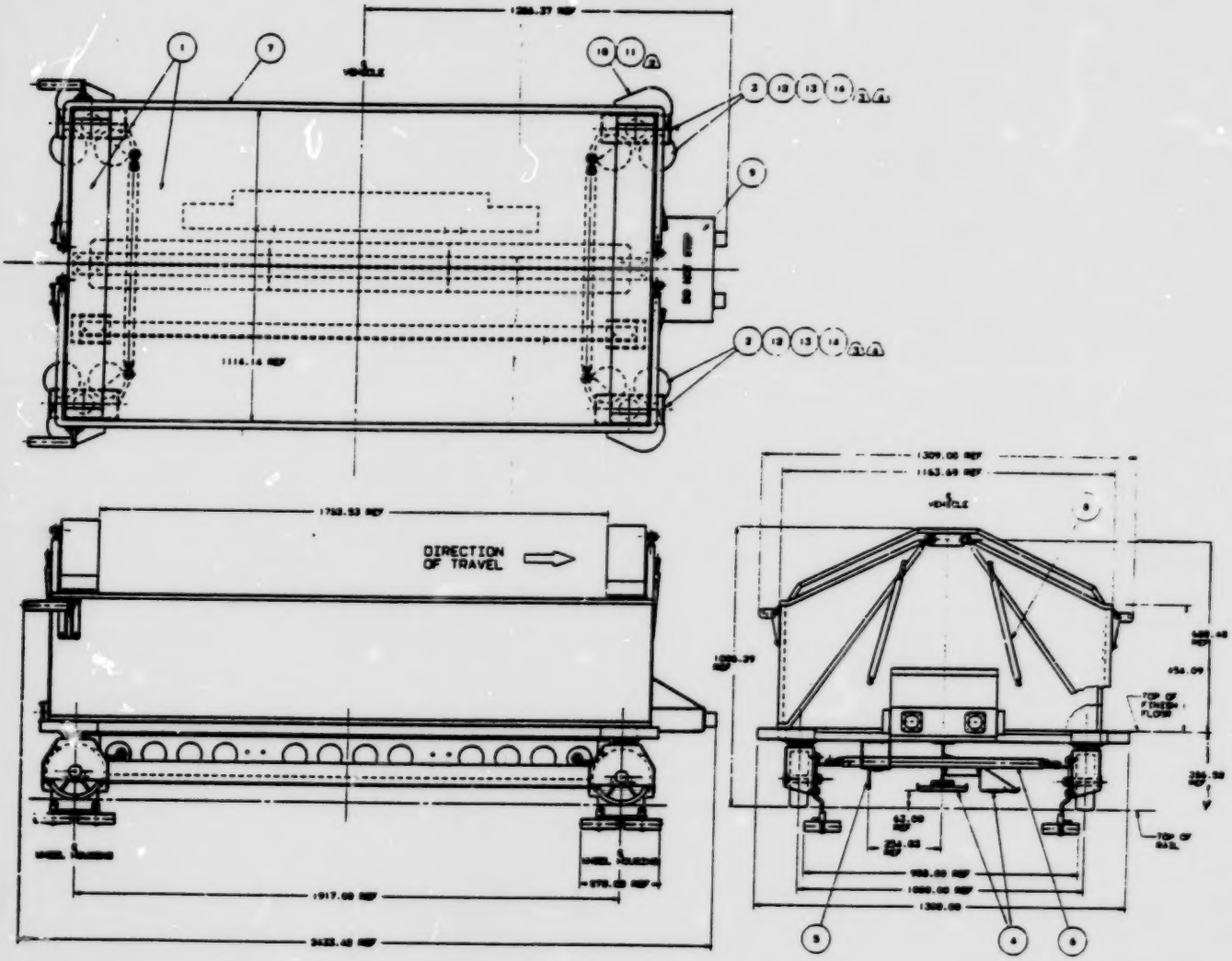


Figure 5: Changi Vehicle

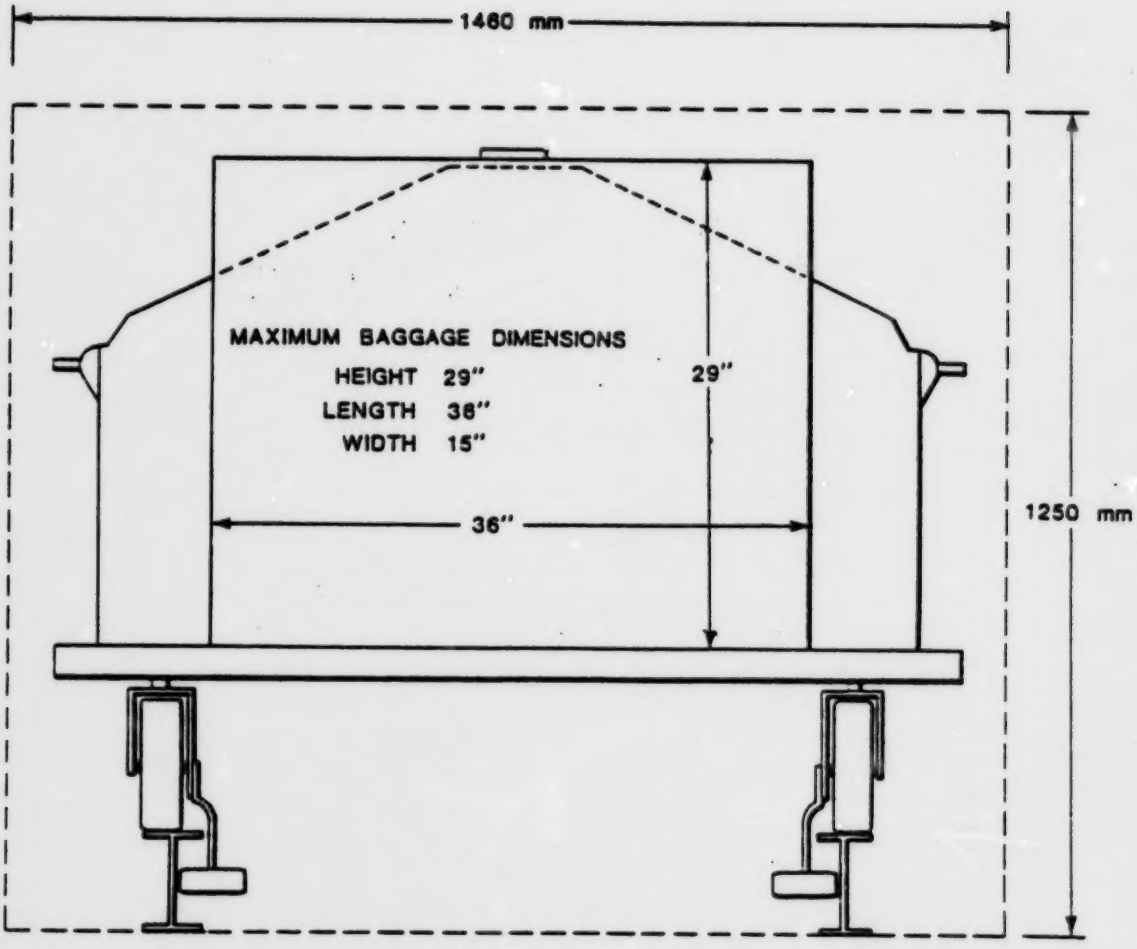


Figure 6: Changi Vehicle Envelope

6.1.4.9 Propulsion and Control

Propulsion requirements are met with two linear motor designs and two permanent magnet designs (PMD).

The control strategy employed is a function of the particular area of operation. Fundamentally there are three levels of control:

- o In cruise sections control is effected by the inherent thrust characteristics of the linear motor/reaction rail combination.
- o In ramp areas, and for adjustment of speed, control is achieve through the use of a voltage controller.
- o Where precision speed or position control is required, use is made of UTDC's voltage controller.

In all cases the control loop is locally based, the requirement provided by the supervisory control. Linear motor spacing is designed to provide for redundancy of units, enabling continuing operation in the event of linear motor or controller failure.

Additionally, permanent magnet decelerators are used to protect downgrades and critical speed zones.

6.1.4.10 Control Communication

Communication between the central computer and the distributed controlling microprocessors is via a multiplex "bit-bus" link in a twisted pair. Local devices and inter-block communication is hardwired.

6.1.4.11 Back-Up

Two battery powered, rubber tired electric vehicles are provided for repairs and for back-up.

6.1.5.0 Evaluation Interterminal Baggage Transport

6.1.5.1 General

The system discussed in this section is the UTDC "Intelimotion Baggage Transport System" which has performed on a full feature demonstration track, and is currently being installed at Changi International Airport in Singapore.

6.1.5.2 Operating Requirements

The current system is deemed to meet all the requirements identified in this study. System availability is not verified but it is predicted that the requirement will be exceeded, and results from an operational system are favourable.

6.1.5.3 Automatic Operation

Normal system operation is fully automatic (note that loading is manual). Only a power failure case requires manual intervention for restart. The system is extensively monitored, far beyond requirements, given the level of health monitoring.

6.1.5.4 Route Feasibility

Dedicated, protected right of way is required. Retrofit may or may not be a problem, depending on the specific airport. In general, the grade and curving ability of the BTS provide a substantial degree of installation flexibility.

6.1.5.5 Technical Risk

At this stage, all major technical risk items have been addressed.

6.1.5.6 System Cost

The UTDC supplied system did not include the tunnel civil work. For the system supplied the price was clearly competitive.

Based on experience to date, a number of measures have been identified which will reduce system cost.

i) In a 1 km system (2.2 km of track) power distribution costs, which are significant, would be reduced with more than one system power supply point.

ii) Small changes in tunnel geometry would have significant impact on propulsion cost (LIM's and controllers).

iii) In order to mitigate risk in meeting reliability requirements, a significant degree of redundancy was incorporated into the design at locations where single point failure would lead to serious system degradation.

If, as expected, reasonable target component reliabilities are met then redundancy may be significantly reduced. Such measures also have beneficial impact on power distribution cost.

iv) In this application, a significant number of scenarios of control will have been encountered, and software developed. New applications will require less control system software development

v) It is feasible to reduce system maximum cruise speed. Various options exist such as:

- o reduce headway
- o increase buffer time
- o optimize LIM/RR for drive.

In general, the result of reduced speed will impact favourably on the number of LIM's, nature of controllers, power distribution, control complexity, etc.

6.1.5.7 Alternative System Comparison

For the distance, capacity and availability required for interterminal baggage transport there appears to be no potential competitive systems. In fact, at Changi both bidders offered LIT systems.

Conveyor systems are too costly, unreliable and slow to fill this requirement.

AGV's operating at 3 to 5 mph (2.2 ms^{-1}) would have excessive trip time compared with the BTS speed of 6 to 12 ms^{-1}. Further, fleet size would enlarge significantly. The energy requirement for higher speed would be prohibitive.

Because of "inside" operation, a power pickup could be employed. In a limited access environment this would be feasible. However, vehicle control and communication presents a very significant challenge for the headways required. To date, no on-board system has been able to cope with these requirements.

6.1.5.8 Mission Viability

Where there is a requirement for interterminal baggage transport, and the investment in guideway is warranted, the BTS is a very effective system for moving baggage.

6.1.6 Conclusions

The BTS as configured appears to be an excellent match for interterminal requirements. Further, it appears that LIM-In-Track presents the only viable system for the capacity required.

At this stage, the BTS is an embryonic product. A significant amount of systems engineering is required to optimize system design and improve cost effectiveness. Operation at 60 Hz will require significant changes to the system. The system components require examination in order to improve cost-effectiveness.

6.2 SYSTEM REVIEW - INTRATERMINAL BAGGAGE

6.2.1 Operations Review

6.2.1.1 General

Since no one has yet devised a way for all passengers to carry their baggage with them on a flight, and most passengers wish to be relieved of it, airlines have developed extensive systems for baggage checking.

The typical objectives of baggage handling systems are:

- Reliability: minimize routing and sorting errors;
- High Performance: ensure passenger satisfaction through speed of handling and processing;
- Economy: increase productivity of processing and handling baggage;
- Security: reduce handling, damage, pilferage and theft, and provide an environment that makes the insertion of weapons into baggage more difficult or, if they are already there,easier to to detect; and
- Convenience: lessen the burden that baggage imposes on the customer.

6.2.1.2 Elements of Baggage Handling

Baggage handling is not a simple operation and involves many handling phases, as can be seen in Figure 7. This flow diagram includes the three main categories of baggage handling:

- direct destination;
- on-line transfer; and
- interline transfer

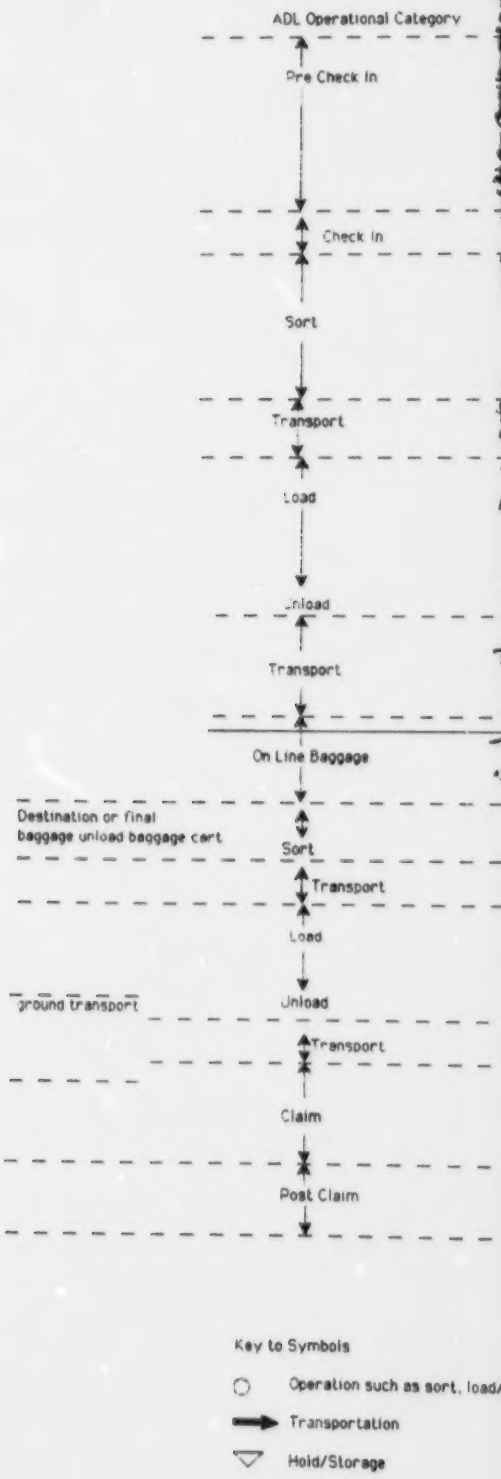
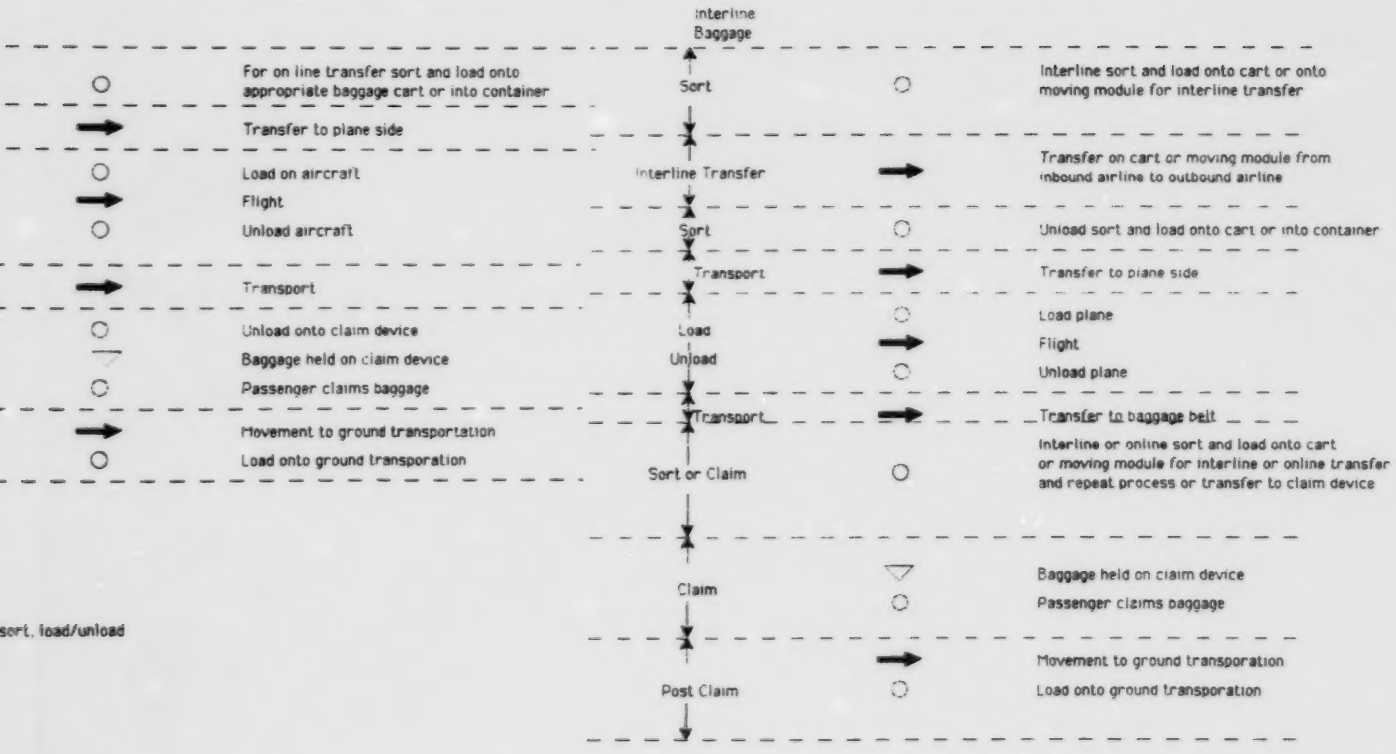


FIGURE 7 : Baggage Handling Flow Diagram

egory	Symbol	Description
	○	Baggage handled by passenger to ground transportation vehicle
	→	Transport to airport; possibility of several transfer points and means of transportation
	○	Unloading bagage from ground transportation vehicle
	→	Carry baggage to check in
	○	Check in baggage at curbside, counter, or gate
	→	Transfer of baggage from checkin by hand, cart, convevor moving module etc.
	○	Manual or automatic sortation and manual loading onto baggage carts or into containers
	→	Movement of baggage from baggage cart to plane side
	○	Loading of bulk luggage from baggage cart into aircrft or loading of containers into aircraft
	→	Flight of baggage to direct destination or first transfer terminal
	○	Unload aircraft
	→	Transport to inbound baggage handling cart. Sort for claim device in case of direct destination bags Sort for on line transfer in case of on line bags Sort for interline transfer in case of interline bags


Interline Baggage
Sort
Interline sort and load onto cart or onto moving module for interline transfer
Interline Transfer
Transfer on cart or moving module from inbound airline to outbound airline
Sort
Unload sort and load onto cart or into container
Transport
Transfer to plane side
Load plane
Load
Flight
Unload
Unload plane
Transport
Transfer to baggage belt
Sort or Claim
Interline or online sort and load onto cart or moving module for interline or online transfer and repeat process or transfer to claim device
Claim
Baggage held on claim device
Passenger claims baggage
Movement to ground transporation
Post Claim
Load onto ground transporation
For on line transfer sort and load onto appropriate baggage cart or into container
Transfer to plane side
Load on aircraft
Flight
Unload aircraft
Transport
Unload onto claim device
Baggage held on claim device
Passenger claims baggage
Movement to ground transportation
Load onto ground transporation

sort, load/unload

It does not include the other baggage handling requirements such as checked baggage for standby passengers, baggage held in hand, or delayed baggage. In these small percentage of instances special steps are taken which result in the baggage either bypassing the standard handling procedure or initiating the standard process after the special procedures have been put in place. It has been decided to exclude consideration of this very small percentage of baggage for the purpose of this study.

Within each of the three baggage handling categories, there are several major aspects of the operation, including:

- Check in: This involves the receipt and tagging of originating baggage by a skycap, ticket agent or gate agent; typically, the luggage is weighed and placed on a conveyor for transfer to a central sort area. These conveyors may be several hundred feet in length. In most airline passenger terminals, the passenger growth has caused installation of conveyor systems in very cramped space and the systems are squeezed and twisted to fit within existing terminal space.

- Sort: This includes the automatic or manual sort of outbound and transfer bags by flight and airline, (refer to Figures 8 and 9) which usually takes place in sorting rooms often cramped with equipment (including conveyor drop shutes, carousels, containers, carts, tow motors etc.) and labourers. The baggage is manually off-loaded from the carousels or conveyor spurs and placed into carts for transfer to aircraft or other terminals.

- Transport: This is the transporting of baggage to and from aircraft and other airport terminals.

- Load/Unload Aircraft: This is the loading and unloading of aircraft with baggage (including any sorting done at the aircraft).

- Claim: This phase involves the positioning of terminating baggage onto the baggage claim devices.

SYSTEM 1

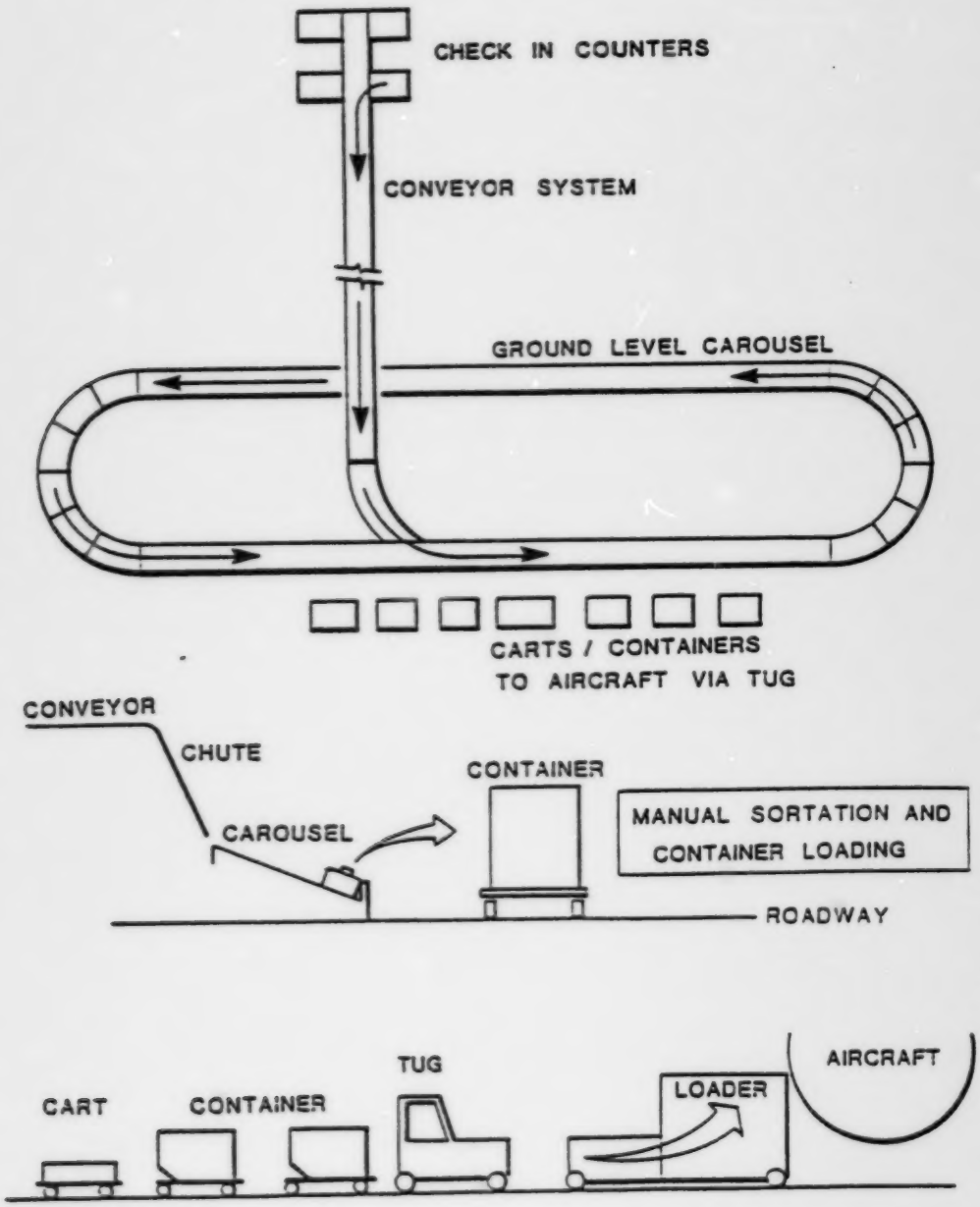


Figure 8: Existing Baggage Handling System A

SYSTEM 2

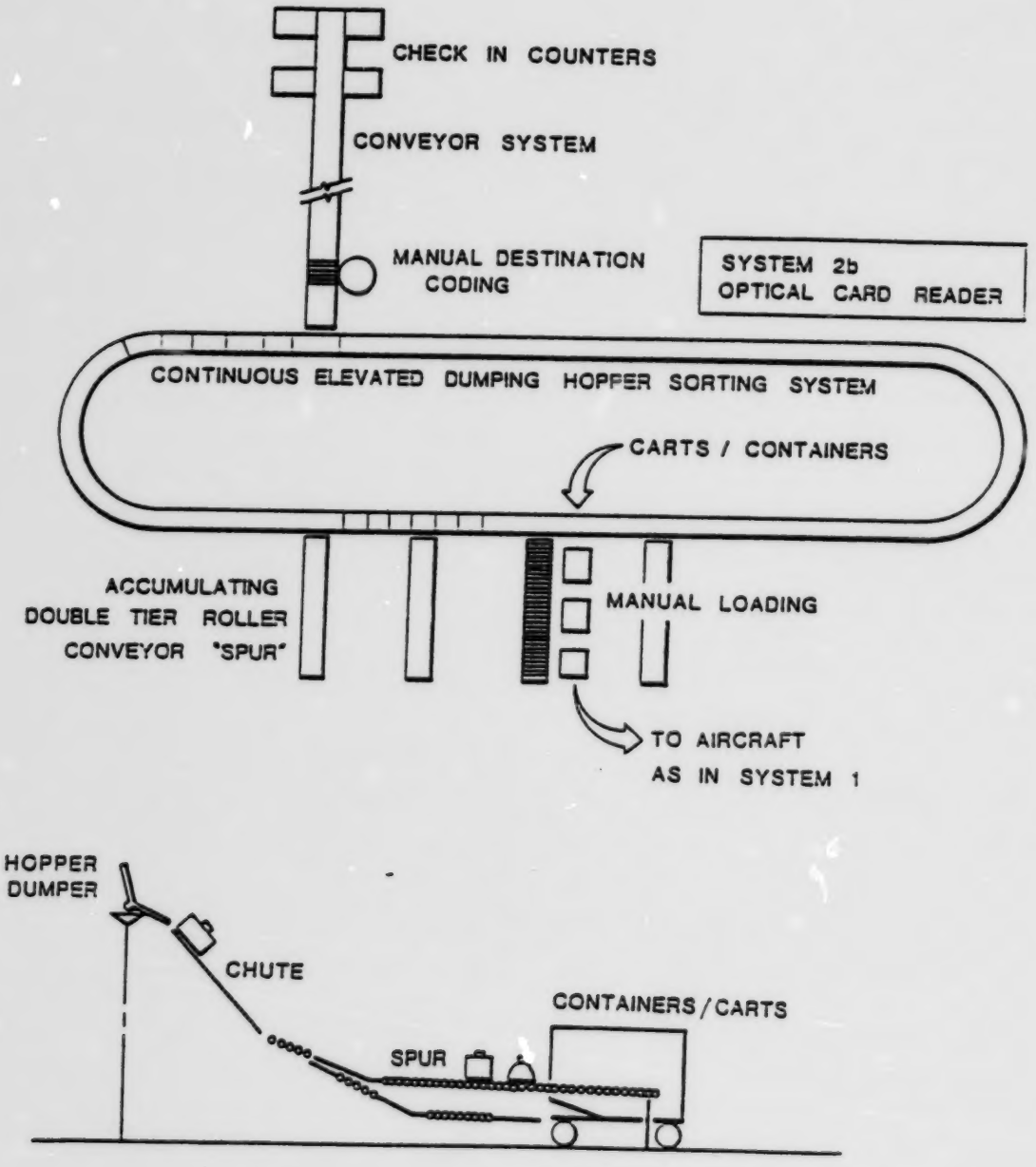


Figure 9: Existing Baggage Handling System 8

6.2.1.4 Problems Associated With Existing Baggage Handling Systems

Conventional conveyor type handling systems, which are used at most airport terminals throughout the world, contain a number of inherent problems which include:

- o Layouts which limit the performance of conveyor systems: Because system installations often are forced to fit within the existing terminal design, the conveyor routing often creates requirements which most conveyor systems have trouble meeting. The result is jamming and breakdowns, causing high maintenance costs and passenger inconvenience.

- o High labour costs: A prime difficulty with conventional handling systems is that they are too labour intensive, which makes them subject to rising labour costs and limits the speed of operation.

- o Tracing luggage after processing: Due to increased security requirements, when a passenger fails to board for a flight, the baggage must be retrieved. This is a time consuming task under existing handling systems, as there is no accurate method of defining which container the specific luggage has been stored.

6.2.2 The Role for LIT

Within terminal operations, it is clear that two major functions are required - transport and sort. Further, a system must be capable of interfacing with the client. Therefore, a small vehicle is required which is dedicated to one passenger's bags.

Figure 10 shows the most extensive system, but in general, the transport distances are of the order of 100 to 500 metres with existing technology. Automatic, and as will be seen later, on-line unloading is required.

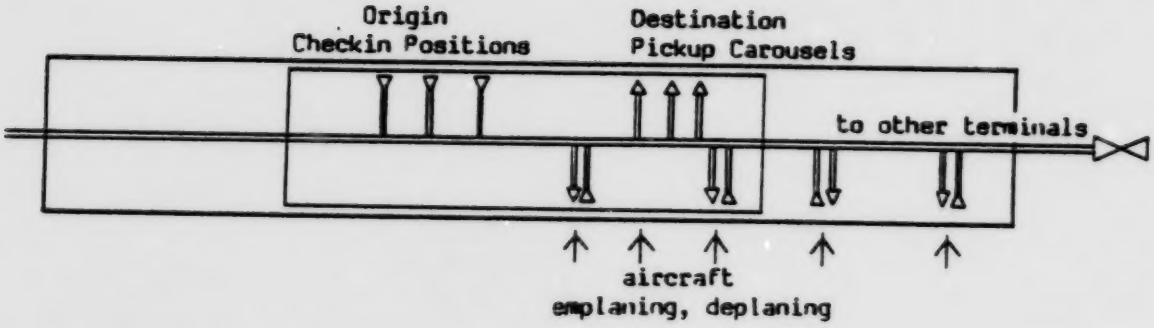


Figure 10: Baggage Handling System

Some potential systems are shown in Table 4 below.

	Passengers	
System A	ORIGIN	Accepts check-in baggage, sorts and delivers to central holding bay area spurs for subsequent hand loading and transport to aircraft.
System B	ORIGIN	Similar to "A" above but delivers closer to gates or at gates.
System C	TRANSFER	Accepts interterminal bags sorted by other means at a central point and transports to correct terminal.
System D	TRANSFER	Accepts interterminal bags at bays and transports to correct terminal gate (spur).
System E	DESTINATION	Accepts destination bags at gate and transports to correct pickup carousel.
System F	DEPLANING	Accepts all bags at gate and transports to correct pickup carousel or terminal gate.

Table 4: Baggage System Definition

In the context of this study it was not practical to examine the role of LIT beyond presenting the baggage to the accumulating spur, i.e., systems "A" and "B".

It is intuitively understood that a system serving these needs would be fully capable of delivering to other terminals (interterminal transport).

6.2.3 Summary of Operating Requirements

The following requirements are extracted from Ref.

- Line Capacity

  4700 bags per hour

- Trip Time/Speed

  5 to 10 minutes
  Speed not critical

- o Acceleration/Deceleration

  No practical limits

- o Grade Capability

  30°, 45° preferred

- o Curving

  Radius 1.2m

- o Load Size

  No bag $>$ .91m x .74m x .38m

- o Load Mass

  No bag $>$ 34 kg.

- o Environment

  Within terminal, but can be exposed to outside temperatures, high humidity and turbine exhaust contaminants.

- o Mean-Time-To-Restore or Backup

  $\ll$ 5 min

- o Availability

  Should be very high

6.2.4 Configuration Summary, Baggage Handling, Intraterminal

6.2.4.1 LIT System Introduction

There is an existing system which accomplishes the outlined requirements, a "handles-up" system. That system has two major drawbacks:

1. the required envelope is 4 ft. x 4 ft., which is larger than a conveyor and renders retro-fit in an existing terminal difficult.

2. the unloading operation requires significant time and complex equipment.

Therefore, in this study, it was assumed that a system would attain considerable competitive advantage if these two limitations were improved.

In response to this challenge UTDC has established a "low profile" (LP) concept as shown in Figure 11 below.

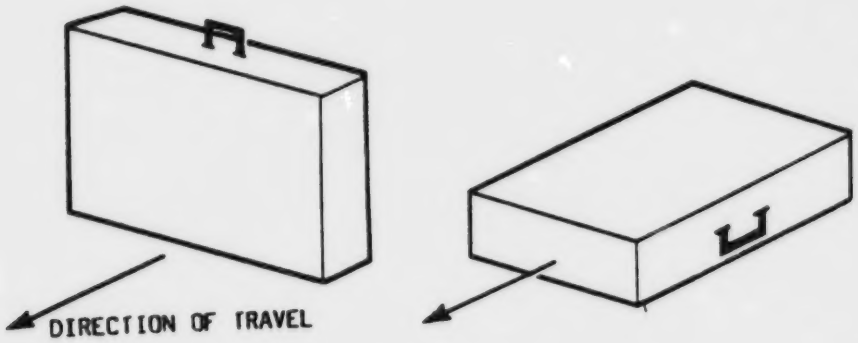


Figure 11: UTDC Low Profile Concept

Examination of Terminal II at PIA shows that there are or can be more than one system operating in parallel. This is because a set of passenger ticket counters is dedicated to a particular kind of service and can usually be associated with particular gates or at least baggage accumulating spur lines.

Therefore, system capacity actually may be of the order of 1800 bags per hour. This may result in fewer than 1800 vehicles per hour, because on average, the vehicle will carry more than one bag.

Nonetheless, this capacity implies headways of two seconds. A block based collision avoidance scheme is, in practical terms, not workable. Therefore the concept involves operation at lower speed, e.g., 6 ms^{-1} allowing collisions.

Only at switches is a fixed separation (less than 1 second) required, and a mechanical separating device is necessary.

In order to minimize the number of spur lines and unloading devices and times, an on-line unloading system is required.

The example configuration is based on the requirements of PIA outgoing baggage through Terminal 2 International Wing (gates 101 through 107) and proposed module "Q" expansion (gates 111, 113 and 115).

6.2.4.2 Model Route

See Figure 12 for the example route. Typical routing features of baggage handling systems were incorporated into this example. Note the following features included in the route:

- o Empty vehicles are supplied to check-in counters for loading and destination identification. Passenger access to the counters will be maintained by installing the empty vehicle supply system below floor level. The track will be raised to convenient loading height within the check in counter area.

- o The outgoing baggage lines from the check in counters are merged into one track.

- o Based on vehicle identification, the vehicle proceeds to

  - the international gates,
  - the "Q" expansion gates,
  - the early baggage holding spur,
  - or spurs in other sections of the system

- o When the baggage reaches its destination, it is unloaded automatically while the vehicle is travelling at low speed on the main line. In this example, the International gates are serviced by seven spur lines in a central location. However, for the "Q" expansion, the baggage is delivered directly to the gates. Note that after the unloading operation, the vehicles will be checked with a sensor to verify that the door has returned to the closed position (i.e. the door is not jammed due to lodged luggage). If the door is not in its closed position, the vehicle will be transferred to the "incomplete unload" spur.

- o Once unloaded, the vehicles return to the check-in area or are temporarily stored in the spur line for extra empty vehicles.

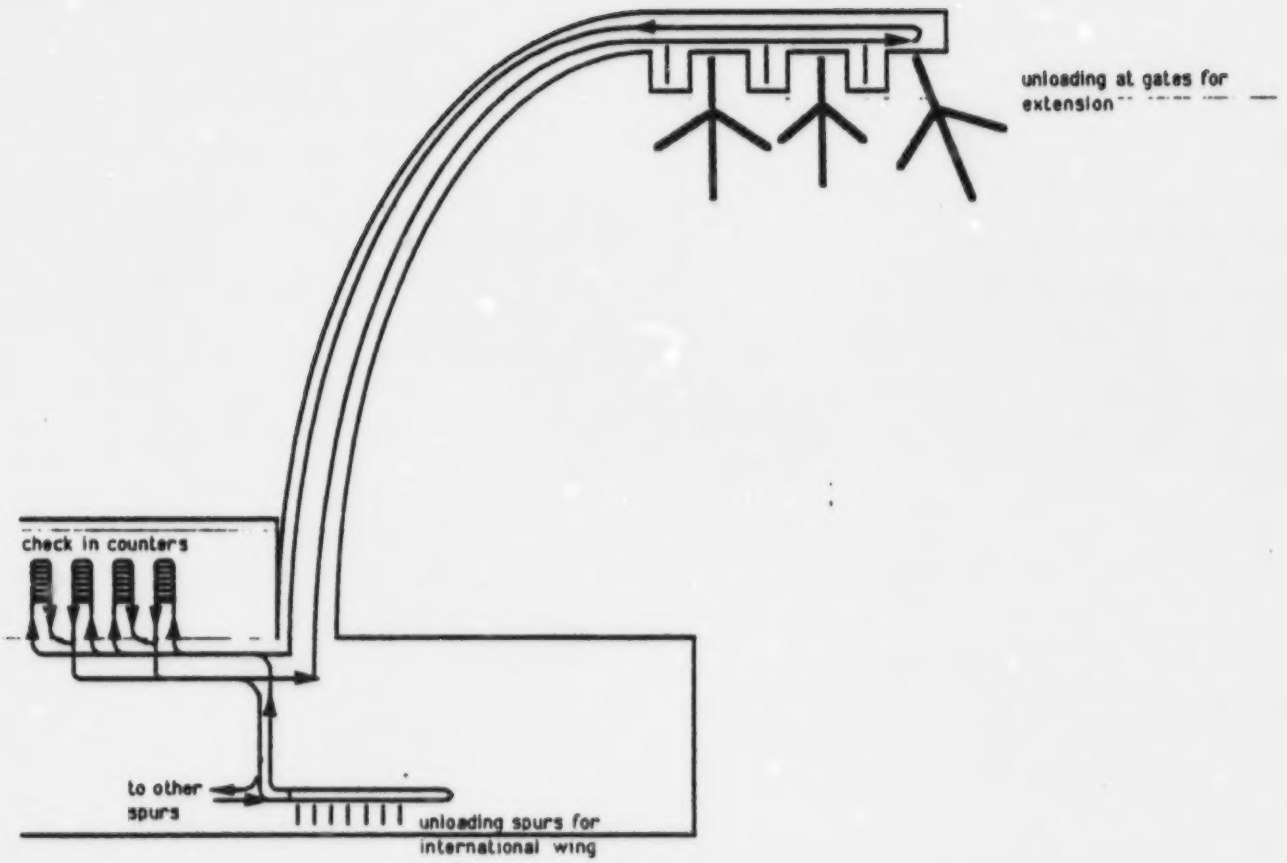


Figure 12: Intraterminal Baggage Handler - PIA

6.2.4.3 Capacity

The required capacity for this example is 1,800 vehicles/hour. The maximum expected capacity for a terminal is 4,700 vehicles/hour, but will comprise more than one system.

6.2.4.4 Speed

The cruise speed of the example configuration is approximately 6 m/s. 6 m/s is more than adequate for the expected applications.

6.2.4.5 Operational Philosophy

The system has the following characteristics:

- lower speed (6 m/s^{-1})
- "sling - shot" propulsion
- passive speed control
- "bumper car" operation
- use of queues
- distributed block control "BCCM" merge points

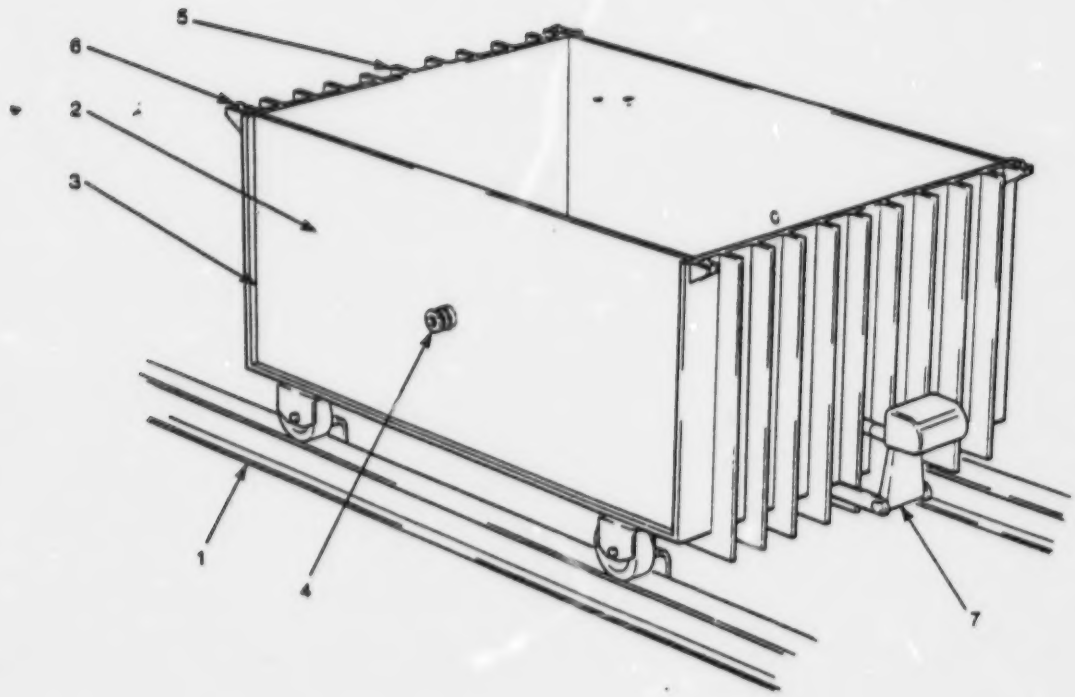
6.2.4.6 Vehicle

The conceptual low profile baggage handler is illustrated and described in Figure 13. The vehicle was designed to carry the maximum allowable size of bag. The baggage compartment is oriented to carry the bag on its side, with the vehicle height and width minimized. Figure 14 shows the vehicle envelope.

6.2.4.7 Track and Guideway Selection

The guideway and track arrangement will be similar to Changi BTS with reduced steel sections compatible with the low vehicle mass. Clearance and ability to unload at unload stations means that the majority of the guideway will be elevated and suspended from the ceiling. Suspension of the guideway may be through inverted portal ('U's) or round bars having couplers for elevation adjustments.

A standard six (6) inch (W150 x 14) steel I-section was used primarily in the Changi BTS. With the smaller loads and reduced wheel base of the Low Profile Vehicle (which increases curving ability), a four (4) inch steel I-section should be sufficient. However, note that the lightest standard I-beam available is the W150 x 14, because of its reduced thickness.



Vehicle Mass (kg): tare=60; gross=94			
Vehicle Dimensions (mm):	length	width	height
baggage compartment	1000	750	400
overall (including running surface)	1600	850	650

VEHICLE COMPONENTS:

1. running wheel, guidance system and track based on Intelimotion concept; 4" I-beam, 4" running wheels, gauge=750 mm
2. side walls (1/4" thick, molded STRUCTHANE 2001) are doors which can be lifted vertically on extending track
3. extending track
4. roller lifting handle
5. end walls and floor molded as one piece (STRUCTHANE 2001, minimum thickness 1/4"; 2" ribs reinforced with fiberglass)
6. rollers on each corner prevent tipping of vehicle on superelevated track in unloading zone
7. bumper units, one on each end of vehicle

note: vehicle also includes two brake rails (for bidirectional vehicle), reaction and sensing rails and tie rods similar to the CHANGI design

Figure 13: Conceptual Low Profile Baggage Handler

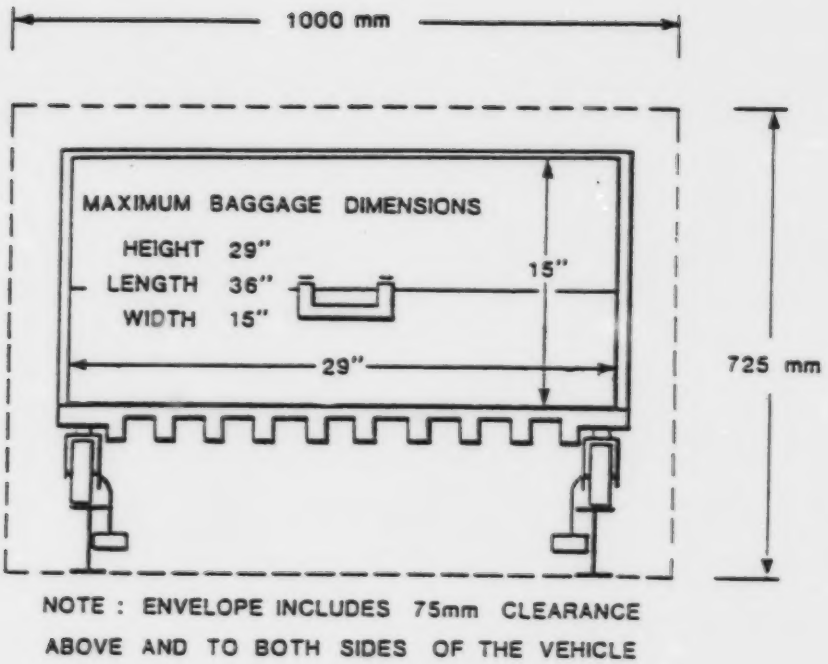


Figure 14: Low Profile Vehicle Envelope

6.2.4.8 Propulsion and Control

The system will utilize 500 N LIMs spaced as required.

The Continental Can Production Cruise LIM, Catalog Number B 52.15 3/3:49 1 has basic characteristics similar to those required by the low profile baggage handler. At 600 V_{11} and 20A, 570 N of static thrust are produced. The duty cycle is 13% for T = 130°. The primary core is 525 mm long and 152 mm wide.

Passive speed control will be utilized where possible. Solid state switches will be utilized in the cruise and acceleration regions. PMDs will be used on any significant down grades to prohibit excessive speed. In vehicle storage spurs, "smart brakes" will be used to control queues. (Brakes will be installed on a down grade;when the brakes are released, the vehicle will roll down the grade.A LIM controlled with a solid state switch will give "sling-shot" propulsion to the departing vehicle). The supply frequency will be reduced in the unloading areas to allow passive control at low speeds (10 Hz would reduce the cruise velocity to approximately 1.0 m/s).

In order to operate switches and the automatic unloading system, the vehicle must, at those locations, be no closer than one second apart. A passive separator has been proposed to provide the required spacing . It is a mechanical device which retards a trailing vehicle when the vehicle spacing is too small.

6.2.4.9 Control Communication

Communication between the central computer and the distributed controlling microprocessors is via a multiplexed "bit bus" link in a twisted pair. Local devices and interblock communication is hardwired. This system is considerably simplified compared with the BTS because of the elimination of block control and collision-capable vehicles. This eliminates a large number of control microprocessors, communications links, LVCM's, and interblock hard wiring.

6.2.4.10 Back-Up

It is not feasible to provide significant back-up for this system (Similar to existing systems). However, it is felt that availability will be higher than existing systems, and MTTR will be lower. Additionally a certain percentage of redundant bypass track can be considered.

6.2.5 Intraterminal Baggage Transport

6.2.5.1 Operating Requirement

With the on-line unloading capability, the "Low Profile" system is entirely capable of meeting the operating requirement. The capacity requirement is clarified to recognize that the terminal will effectively employ several systems.

6.2.5.2 Automatic Operation

This system is fully automatic in normal operation and can be expected to provide an auto-restart capability from all down situations. In general the monitoring requirement is not high, especially if the system is designed to cope with reading errors.

6.2.5.3 Route Feasibility

The profile of the system enables installation in competition with conveyors. Therefore, retrofit is feasible.

6.2.5.4 Technical Risk

In many respects, the system is simpler than the BTS, but certain capabilities discussed below, have not been demonstrated, and are at the level of conceptual design.

6.2.5.4.1 On-Line Unloading

A number of mechanical and electrical issues require demonstration. The "Sailrail" installation at the UTDC site used variable frequency controller and "swept" the frequency range to provide jerk free acceleration and braking. Therefore we have confidence that continuous operation at a low (eg 10 Hz) frequency is feasible. The operation of an on-line door lifter and operation of the door, or other option, would have to be developed and demonstrated.

6.2.5.4.2 Ticket Counter Interface

Considerable detail design, mockup and test is required to establish a "user friendly" and practical interface design for this format of vehicle.

6.2.5.4.3 Vehicle Separator

This device ensures that there is a minimum vehicle separation before switches. The conceptual designs would require at least detailed examination to establish confidence in their feasibility.

6.2.5.5 System Cost

A typical section of the system track, including allowance for vehicles, propulsion and control, will be less costly than the BTS or an existing conveyor system. The system total cost requires check-in interfaces and will be site specific. The system includes sorting capability, however, to be a system, the conveyors must be joined by optical card reading units and load sorting and discharging mechanisms.

It is clear that conventional systems are required to be centralized for cost and reliability reasons, whereas the LP is capable of delivering the bags directly to the gate.

6.2.5.6 Alternative System Comparison

For a system with (i) a large number of vehicles and (ii) operation at headways of 1 to 5 seconds, power on-board is not practical.

Mechanical wayside-based systems have not shown promise except in the format of the existing installed systems.

The LP system offers the potential, based on the previous discussion, to be cheaper, faster, more reliable, incur lower maintenance hours than existing systems and to provide the ability to take the baggage to disparate points.
(This is well illustrated in the example system based on Terminal II expansion).

An additional advantage is the option of using the LP as the interterminal system.

6.2.5.7 Mission Viability

The LP system essentially fulfils an existing mission, therefore it is deemed viable.

6.2.6 Conclusions

The LP system appears to meet all the requirements, it will be less costly than the BTS or conveyors, can be retrofit at existing airports and can offer airport designers new opportunities.

It can also serve as an interterminal system, integrated with a within-terminal system. It may also serve a role for deplaning passenger baggage.

6.3 SYSTEM REVIEW - AIR CARGO

6.3.1 Operations Review

6.3.1.1 General

Several operational changes or aspects over recent years have altered or influenced air cargo patterns. These include:

- o deregulation of the U.S. domestic airline industry;
- o the growth and expansion of the small package/express carriers;
- o the curtailment of night-time operations, air traffic control limitations, etc.: and
- o a major shift to hub/spoke route systems.

The mergers, acquisitions and interline agreements in the passenger airline sector have not only gathered captive passengers, but they have also created the availability of sizeable amounts of cargo space controlled by one operator. As shown in Figure 15, the major airline with its added system segments can now command a significantly larger share of the available market for both passengers and cargo.

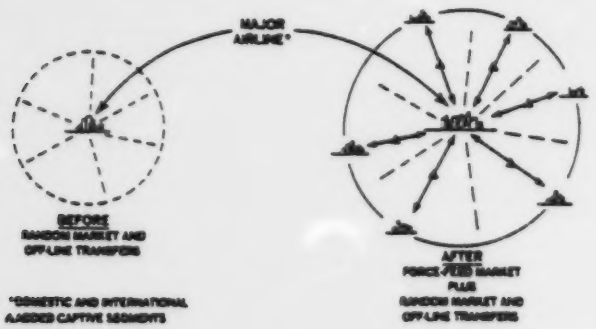


Figure 15: Mergers, Acquisitions, and Interline Agreements

6.3.1.2 Elements of Cargo Handling

Regardless of whether by passenger, express, or freight carrier, air cargo will basically flow from origin to destination via one of the routings shown in Figure 16.

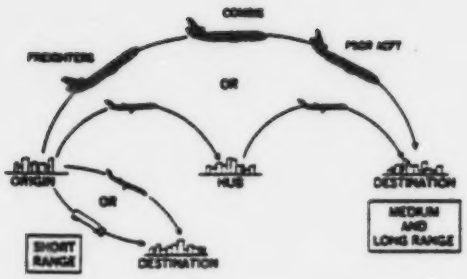


Figure 16: Air Cargo - How Does it Move?

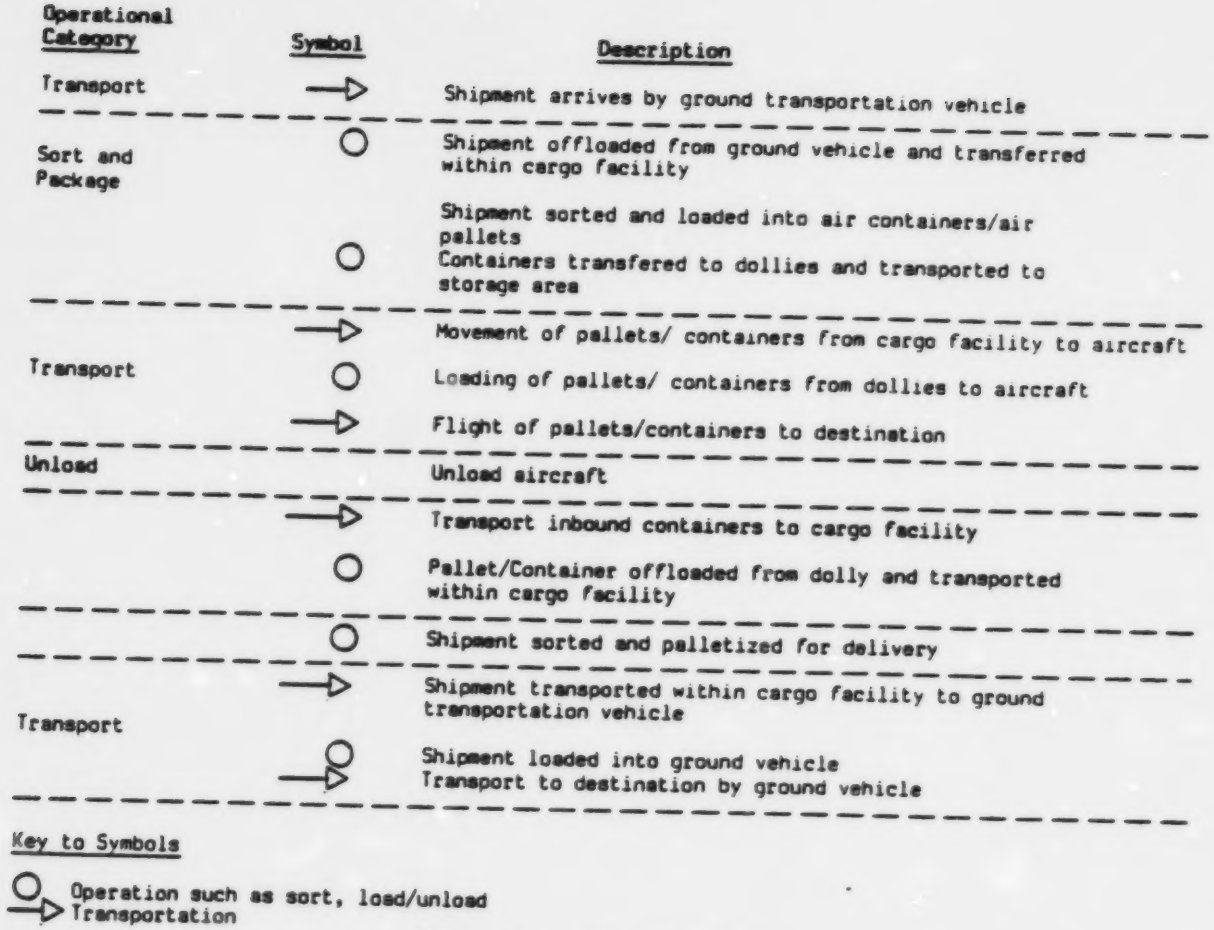

Operational Category
Symbol
Description
Transport
Shipment arrives by ground transportation vehicle
Sort and Package
Shipment offloaded from ground vehicle and transferred within cargo facility
Shipment sorted and loaded into air containers/air pallets
Containers transfered to dollies and transported to storage area
Transport
Movement of pallets/ containers from cargo facility to aircraft
Loading of pallets/ containers from dollies to aircraft
Flight of pallets/containers to destination
Unload
Unload aircraft
Transport inbound containers to cargo facility
Pallet/Container offloaded from dolly and transported within cargo facility
Shipment sorted and palletized for delivery
Transport
Shipment transported within cargo facility to ground transportation vehicle
Shipment loaded into ground vehicle
Transport to destination by ground vehicle
Key to Symbols
Operation such as sort, load/unload
Transportation

Figure 17: Cargo Flow Diagram

Cargo handling within the cargo facilities evolves through several phases, as can be seen in Figure 17. The major segments of the operation include receiving of the export shipments, sorting and packaging the goods onto aircraft pallets or into airfreight containers, transporting the shipments to the aircraft, and loading the goods for the flight. At destination, the reverse procedure is used for arranging delivery to the customer. In the past, the movement of goods from the cargo facility to the aircraft was a relatively short distance as cargo facilities were typically within the airport property and cargo planes had close access to the cargo building. This transfer distance is rapidly expanding with the increase of passenger aircraft used for moving cargo, which necessitates that the cargo be transported to passenger loading gates. Also, with the tremendous demand increase for airport space, cargo facilities are now being located outside the airport perimeter. This situation significantly changes the operational needs for moving cargo between the facilities and the aircraft loading area.

6.3.2 The Role for LIT

A transport system for freight, or air cargo may fulfil one of three roles which are illustrated in Figure 18, using PIA as an example.

Route A

It is approximately 2.6 km from the Vista air cargo facility to a central point near the passenger terminals. At controlled speeds, using present methods, this could represent a twenty minute trip time, each way. An automated system would eliminate the labour cost associated with the trip, and reduce travel time significantly.

Route B

This route is representative of the use of an air cargo system to enable exploitation of off-site land. In this case the system would be required to handle all air cargo, including that shipped on all cargo aircraft. This would require a branch line.

Route C

This route is representative of the use of the land available on the infield. A tunnel is required to provide access.

6.3.3 Summary of Operating Requirements

The following requirements are extracted from Reference .

- o Line Capacity

  120 pallets per hour

- o Trip time/speed

  trip time not critical speed 25 km/hr

- o Acceleration/Deceleration

  No practical limits

- o Grade Capability

  Up to 8%

- o Curving

  Radius of 20m

- o Load Size

  Pallets 88 x 125 inches
  and 96 x 125 inches

- o Load Weight

  Less than 15,000 lb gross (6802 kg)

- o Environment

  Operation is outdoors, all year

- o Back-up/MTTR

  Restore in less than 30 min.

6.3.4 Configuration Summary

6.3.4.1 LIT System Introduction

The nature of the vehicle is dictated by the cargo size and mass, and the all-weather operation.

Conventional steel wheel/rail is selected, at an appropriate diameter of .38m.

For the heavy loads, the two pallet vehicle configuration has significant operational benefits, enables steering to reduce noise on tight curves, and enables low height. The vehicle is configured with conventional pallet handling components, rollers and tie downs.

High speeds are not required, and selection of 6 ms^{-1} significantly reduces propulsion costs. Operation and control is similar to the BTS except that because of the low frequency a three block collision avoidance scheme is feasible. This scheme has the advantage that it is essentially adaptive in terms of flow control.

One feature which can be used is a "level crossing" capability which is thought to be compatible with operations within the restricted side of an airport.

Loading and unloading can be manual or automatic.

The example system is based on general freight requirements using PIA as an example.

6.3.4.2 Model Routes

Two alternate routes will be considered in the example. They are illustrated in Figure 6.1. The first is from A, Vista, to the Central Location and the second is from C to the Central Location.

Assume that the first route is 70% at grade and 30% is elevated. Assume that 40% of the second route is at grade and 30% is elevated. Sections of the second route are in a tunnel under the runway (assume 30%). Double track is used in both examples, one track dedicated to each direction, with the exception of the tunnel which will be a single track to minimize the tunnel size required.

6.3.4.3 Capacity

The required capacity is 60 pallets/hr/direction. Note that to meet this capacity, the headway in the bi-directional single track will have to be reduced.

The maximum expected capacity in a comparable system is 120 pallets/hr/direction.

Figure 18: Freight System - PIA

6.3.4.4 Speed

The cruise speed will be 6 m/s. This is adequate to meet the needs of freight applications.

6.3.4.5 Operational Approach

The system has the following characteristics:

- lower speed (6 ms^{-1})
- "sling shot" propulsion
- passive speed control
- 3 block collision Avoidance Scheme (CAS) double failure philosophy
- use of queues
- distributed block control "BCCM"
- bit bus communication link.

6.3.4.6 Vehicle

The freight system is based on UTDC's Low Capacity Transit System (LCTS) which meets the following basic requirements:

- LIM in track vehicle
- all weather operation
- steel wheel/rail
- 20 m radius curving

The chassis of the LCTS will be utilized and the passenger modules will be replaced with platforms. The maximum pallet (container) size is 125" by 96", therefore, one pallet could be carried per platform or two pallets per vehicle.

The platform will be constructed to minimize height while keeping a simple structure. Figure 19 illustrates the structure. Two hollow square structural steel sections will run the length of the platform. They will be positioned approximately 1.0 m apart to allow clearance for the ring bearings in between. A bent plate structure will connect the longitudinal square sections to the ring bearing. Four hollow rectangular steel sections will run laterally across the platform and will be welded on top of the longitudinal sections. These sections will also be positioned to allow clearance for the ring bearing so that a portion of the lateral sections can be below the top of the bearing. A channel containing rollers will be mounted on top of the lateral sections. The rollers will allow for lateral loading and unloading of the pallets. The pallets will be secured when they are on the vehicle.

The mass of the vehicle has been estimated as follows:

o	vehicle chassis	1,310 kg
o	platforms (2)	1,314 kg
o	maximum pallet mass (2)	13,636 kg
	Crush Load	16,260 kg

The crush load is approximately two and a half times the crush load of 6,575 kg of the original LCTS design. The increase in load will require an increase in the diameter of the wheels to about .38 m from .28 m. As well, other sections of the chassis may require upgrading to support the increased load.

The suspension system utilized for the LCTS could be modified to reduce the height and allow clearance for a portion of the platform structure to be lower than the ring bearing. The suspension could be simplified due to the reduced ride quality requirements for freight.

6.3.4.7 Track and Guideway Selection

The track for this system will incorporate lightweight (60 lb/yd) continuously welded rail set at standard 1435 mm gauge. The track support structure details are dependent on guideway details and are described later in this section.

The guideway type (i.e., at-grade, elevated and tunnel) will be governed by the required alignment. The first step in the selection of a route or routes for freight movement is to consider the existing routes for movement of cargo. These in general are all at-grade common routes. The most simple and relatively low cost guideway for the Cargo Handling System (CHS) would be conversion of the existing routes to dedicated right of ways, if possible. In such a case, a simple concrete track base (slab) would support the running rails through direct fixation. The concrete slab would be approximately 2.5 m wide and 200 mm thick. The LIMs and other wayside equipment would be attached to the concrete slab through appropriate brackets and anchors.

The simplified scenario outlined above (i.e., total at-grade guideway), is unlikely to happen very often. In most cases the track may have to be crossed at several locations by road traffic. Such crossings would possibly require an embedded rail arrangement and safety gates depending on their location and nature of traffic (i.e., airport employees or public). Nature of the traffic is significant since if it is airport employees only, they can be trained to use the crossings safely, or operate opening/closing of the gates from wayside and so on.

On occasions the guideway may have to be elevated or underground, to clear obstacles. The track arrangement underground would be similar to at-grade. In most cases a cut and cover tunnel would be appropriate due to the relatively shallow depth of tunnel.

When portions of the guideway require to be elevated, the selection of guideway structure and materials will be based on mainly:

- o aesthetic requirements
- o span length
- o cost

For the mass per unit length of the CHS vehicle the optimum cost for a steel structure, used as an example, is with a span length of about 20 m (see "Effect of train mass per unit length on a Guideway Design and Cost; 597-700-320). The track and LIM fixation details on the elevated track are dependent on the type of structure. It would be either of direct fixation or embedded rail.

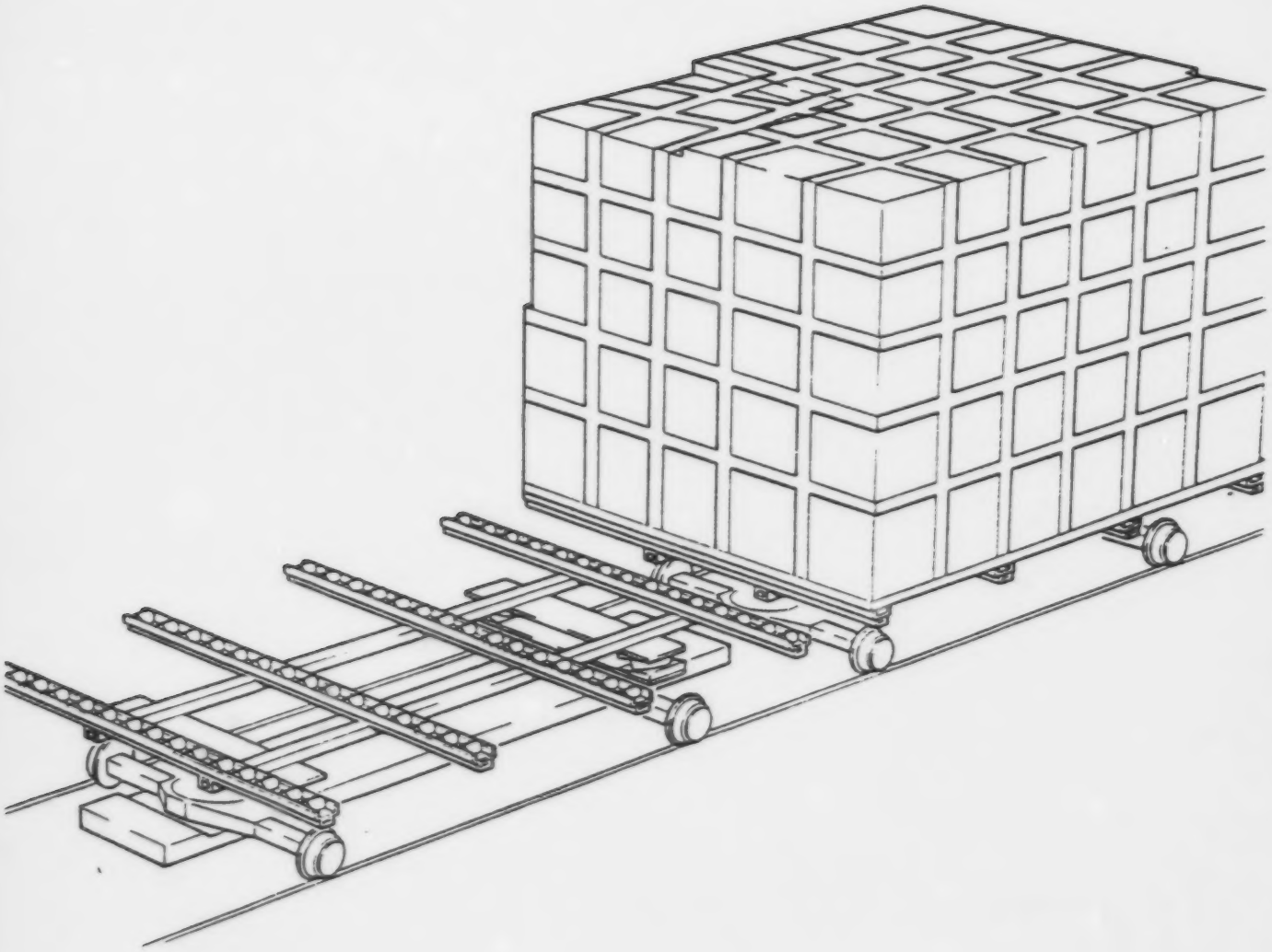


Figure 19: Platform Structure

6.3.4.8 Propulsion and Control

The example systems will utilize 6 kN LIMs in the cruise and acceleration regions. In the cruise region, the LIMs will be 16 m apart and will be controlled by a Solid State Switch and Reversing Contactor. In the acceleration regions, the LIMs will be 8 m apart and will be controlled by a SSSW.

2 kN LIMs will be utilized in braking, manoeuvering and queue regions. They will be controlled with LVCMs. PMDs will also be used in braking regions.

The Materials Handling 6 kN LIM, catalogue # B110.30 3/3:9 2, has basic characteristics similar to those required by the freight transportation system. The copper top cap configuration (2) was selected to increase the slope of the thrust curve around the synchronous speed. This characteristic decreases the speed difference between high and low drag vehicles in a passive speed control system. The primary core is 1095 mm long by 305 mm wide and the LIM has a nominal thrust of 6 kN and a nominal duty cycle of 6% at 600 V_{11}. The peak thrust of 6340N was estimated at 2 m/s and 162A from simulation work.

The Continental Can Production Slope LIM, catalogue # B52.30 3/3:17 1, has basic characteristics similar to those required for the 2 kN freight LIM. The primary core is 525 mm long by 305 mm wide and delivers 2400N of static thrust at 85 A and 600 V_{11}. The duty cycle is 6% for T = 130°.

6.3.4.9 Control Communication

Similar to the BTS

6.3.4.10 Back-Up

The mean-time-to-repair will be adequate, therefore back-up is not required.

6.3.5 Evaluation

Cargo System

6.3.5.1 Operating Requirement

The operating speed of 5 ms^{-1} offers, on the long route proposed, trip time of less than 10 minutes. This trip time is considered acceptable for an automatic system.

The maximum capacity of the example system is 60 pallets per hour,requiring 2 minute headways. Capacity well beyond the maximum requirement of 120 pallets/hr are achievable, but require a higher level of propulsion in the track.

The 20 m curve radius is achieved with full steering, thus reducing noise in curves. Switching is to normal rail practice.

System availability, based on 20 hours of operation per day is expected to be in excess of 99%. In general, the vehicle is simple and the propulsion system embodies significant redundancy. Further, the system, with steel wheels on steel rail/LIM propulsion, is capable of dealing with adverse weather. It is recognized that reasonable operational strategies are required to cope with extreme conditions.

Positive and negative grade of 8% are readily accommodated, and grades more than double that are feasible, but lead to a higher propulsion investment. (LIMs, controllers, power cable).

6.3.5.2 Automatic Operation

In system operation terms, the system proposed is extremely simple and reliable. Experience has shown that such a system requires a minimum of monitoring. Because of system length and cargo criticality, continuous monitoring is recommended. Maintenance personnel may be shared, provided they are on site, because of the necessity of achieving a reasonable MTTR (Mean time to repair).

6.3.5.3 Route Feasibility

It appears that much of the route can be built at grade along natural boundaries. The concept of user-initiated level crossings appears feasible, especially where the system is airside, and only employees would use the facility.

At PIA, for example, with the building of Terminal 3, certainly an elevated section would be recommended to clear automobile traffic.

A more difficult scenario exists at the passenger terminal where it is desireable to be as close to the aircraft as possible. The loading and unloading functions cannot interfere with other normal activities.

6.3.5.4 Technical Risk

All of the major elements of the system have been built and many tested, in one form or other. Element reliability has not been

established with confidence, because insufficient operating time has been accumulated.

A critical requirement is outside operation, with the consequent effects on LIM's, sensors and controllers. A small system was operated through one winter, with positive results.

There is confidence in the vehicle, since the conventional steel on steel technology is to be applied.

Overall, it is judged that the system can be designed to meet its requirements.

6.3.5.5 System Cost

The freight system cost will be dominated by the guideway and track cost. The system is lightly loaded and contains extensive cruise sections, therefore propulsion and power distribution costs are expected to be relatively low. Consequently, system cost will depend primarily on how much of the right-of-way is at grade, the least expensive form. Based on the headways, it is feasible that sections of right-of-way be single track, although this adds to the propulsion and control costs. An example of single track which would be particularly cost effective is a tunnel section. Additional propulsion costs are ameliorated by using the grades to accelerate and decelerate cars.

The transfer station near the passenger terminals will require detailed design at a site.

6.3.5.6 Alternative System Comparison

Historically, it has been understood that automatic rubber tired systems will prove unreliable in winter conditions, and on-board propulsion systems encounter system reliability issues as the number of vehicles increase, and require means to protect the power pickup in adverse weather.

The wire-following AGV option would cope if a heated or covered guideway were provided, both of which are not trivial requirements. In general these vehicles require significant maintenance and battery charging time. Given the speeds and loads the energy storage requirement will be one order of magnitude beyond existing vehicles. It would seem, therefore that a power pickup is required, which leads to considerations of human protection. Our experience shows that LIT systems can be mixed with shop personnel and equipment in certain circumstances.

Therefore, alternative systems do not appear feasible.

6.3.5.7 Mission Viability

Given the operational scenario, the loading can be performed off-line and manually. Further, the system can automatically deliver the pallet to a central location or locations. The viability of the system hinges on the comparison of transport cost versus the cost and complexity of the control operations and savings related to off-site warehousing.

If the shipment of pallets is well synchronized with the aircraft loading facilities, then a minimal number of buffer storage spaces are required.

To answer this question will require a full operations analysis of the aircraft loading cycle.

6.3.6 Conclusions

Although the air cargo system is a novel application of the LIT technology, the components and proposed method of control are based on existing technology. Therefore, there is confidence that the LIT system will provide a viable transport technology.

The key questions relate to the system interface, primarily at the tarmac end, and the overall cost-effectiveness.

6.4 SYSTEM REVIEW - PASSENGERS

6.4.1 Operations Review

6.4.1.1 General

The tremendous growth in passenger airline traffic is placing great pressures on existing airport facilities to handle the large passenger volumes. Forty percent of the greater than 3,000 U.S. airports are reporting capacity problems and market projections indicate that the number of U.S. passengers will increase by approximately 70 percent between the years of 1987 and 1996. At many airports there are serious space constraints at curbsides, check-in stations, parking areas and airline gates, resulting in poor quality service to the customer.

To improve the situation, existing terminals are being enlarged and/or new terminals are being built. The consequence of this is larger travel distances within and between terminals, which adds to the problem of getting passengers and baggage to and from the aircraft.

6.4.1.2 Passenger Transfer Requirements

With the continuing growth in air travel, so grows the need to provide reliable and efficient transfer services within the airport confines. Figure 20 is a flow diagram of the basic steps a passenger must undertake, taking a flight. Many of the steps involve transfer from one location to another. Particular areas of need include:

- Parking Lot to Terminal Transfer: With increased traffic volumes, airport parking is expanding to locations where passengers must walk a considerable distance to the terminal or wait for transfer vans to transport them. Passengers require accessible, reliable and short interval service which will quickly deliver them to the terminals.

- Intraterminal Transfer: Due to the increased size of terminals, passengers often must walk long distances within the general terminal area or in the concourse areas leading to the gates. There is an ever-increasing need for a reliable, accessible transfer system within terminals.

- Interterminal Transfer: The construction of additional terminals at airports to handle traffic volumes has significantly increased the need for passengers to travel between terminals. Due to curbside tie ups at many airport locations, the installation of bus systems should be seriously questioned.

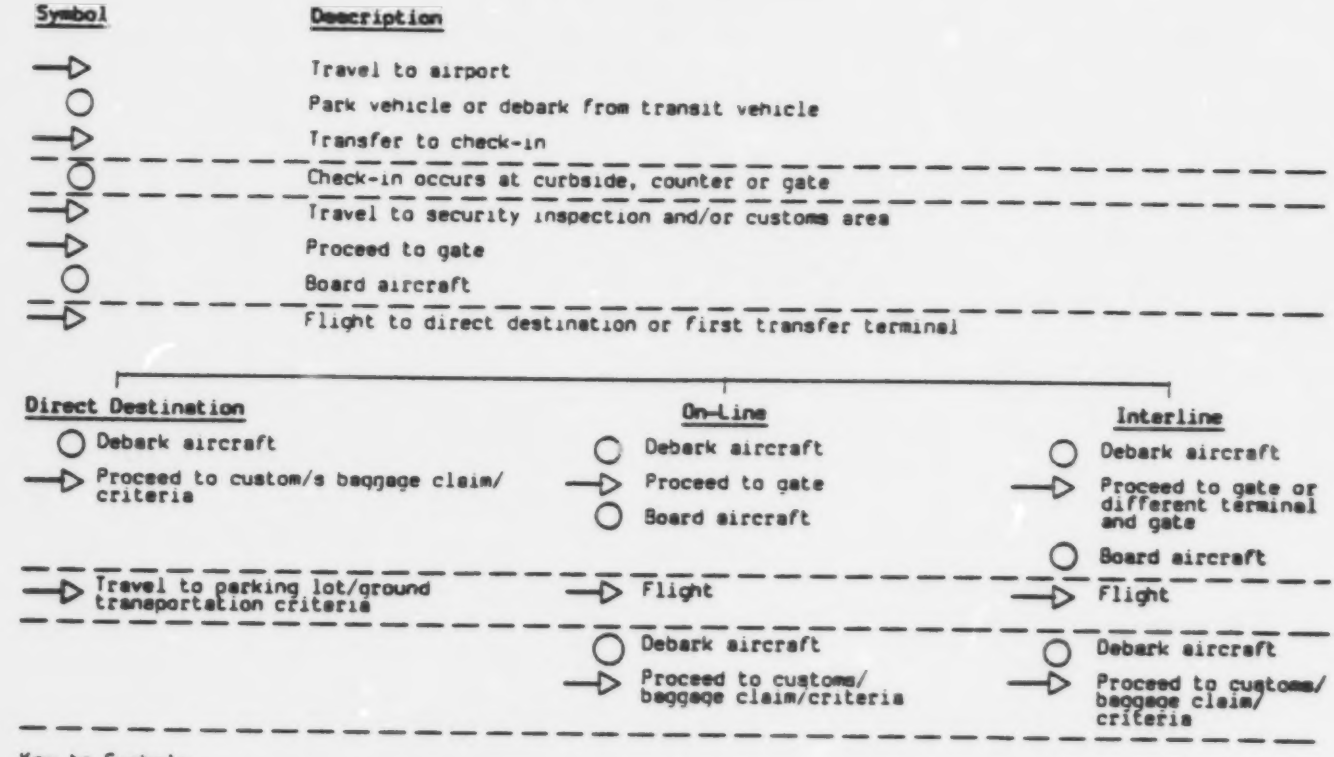


FIGURE 20: Aircraft Passenger Flow Diagram

6.4.2 The Role for LIT

The primary LIT system advantage is cost-effective, high frequency service in loop configuration where capacity requirements fall below those provided by conventional AGT systems.

6.4.3 Summary of Operating Requirements

- Line Capacity

  Practical capacity of 3,000 to 10,000 pphpd.

Note 1: The system capacity allows fewer passengers per square metre to allow for baggage.

Note 2: Earlier work by UTDC has suggested that lower capacity systems have wide application, but are generally not practical using conventional technology.

- Trip Time/Speed

  Approximately 13 ms^{-1} maximum speed

- Acceleration/Deceleration

  1. to 1.5 ms^{-2} jerk limited

- Service Interval

  $\leqslant$ 2 minutes

- Grade Capability

  Performance on 6% grades
  Cope with 8% grades

- Curving

  Radius $<$ 20m

- Environment

  All-weather

- Availability

  A = .99
  MTBF = 12.00 hours
  MTTR = 0.12 hours

- Other Criteria

  To transit standards

6.4.4 Configuration Summary

Introduction

The vehicle is designed to service the lower end of the capacity requirements. As a passive vehicle, the small vehicle does not provide the same cost penalty as one incorporating propulsion and control onboard. The steel wheels on conventional track with curving capability are designed to provide low noise on tight curves, while coping with adverse weather.

This particular design selects an optimum mass per unit length which, combined with the operational speed is expected to reduce guideway cost, but which provides for transit standard evacuation (compared with monorail). All standards are to at transit level except for baggage space appropriate to the airport scenario.

The control system proposed is simple.

The example configuration is based on the requirements of Newark Airport.

6.4.4.1 Model Route

The route types typical for airport people movers include:

- single loop
- dual loop
- multi loop
- pinched loop
- shuttle
- shuttle/loop

The route type for the example configuration is pinched loop. See Figure 21 for the Newark route. This type of route is the most common in the industry.

Table 5 contains the route chainage and the station spacing. For Newark, the maximum station spacing is 625 m. Typical station spacing in the industry is 200 to 800 m.

6.4.4.2 Capacity

The initial system capacity requirement is 1,000 pphpd, expandable to 2,800. The typical capacities of a broad range of people mover installations range from 500 to 10,000 pphpd.

6.4.4.3 Speed

The cruise speed of the example configuration is 12 m/s. This is consistent with the top speeds seen in people mover specifications.

6.4.4.4 Control Philosophy

Four control philosophies are available for the system:

- station clear
- station arrive
- station clear plus
- station arrive plus

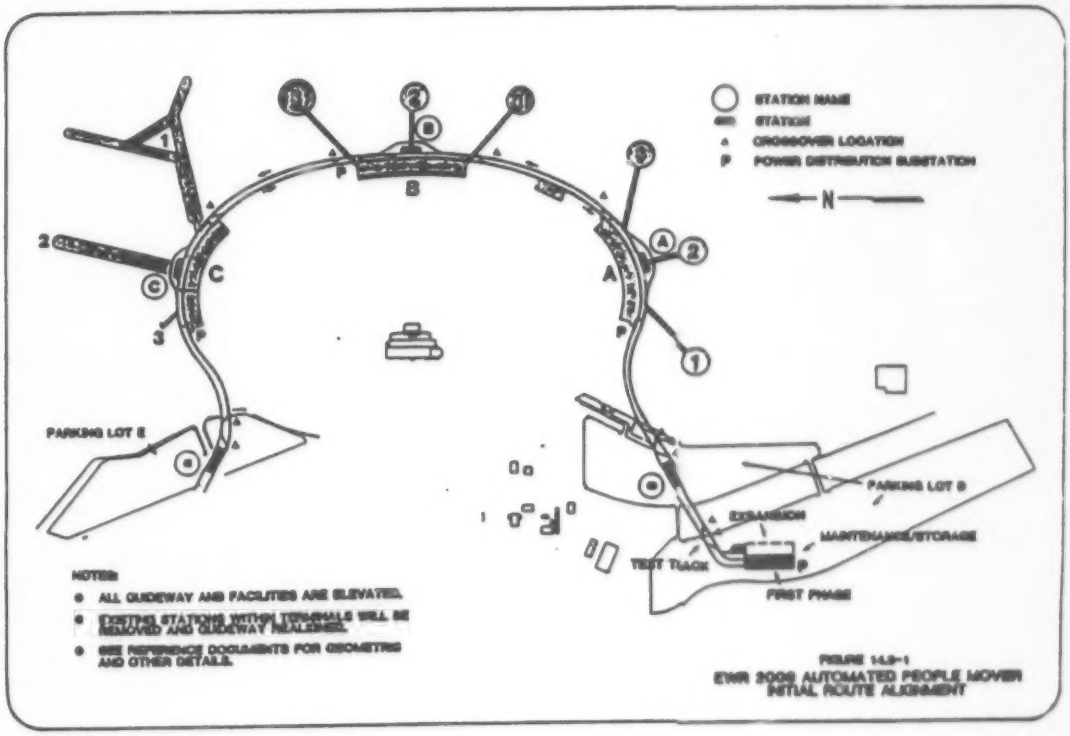


Figure 21: People Mover Route - Newark

Station	Chainage (ft)	Spacing (m)
Parking Lot E	250	
		472
Station C	1,800	
		625
Station B	3,850	
		625
Station A	5,900	
		579
Parking Lot D	7,800	
		353
Maintenance	8,959	

Table 5: People Mover Route - Chainage and Spacing

Based on earlier work, a control policy station clear was selected for this example. It is the simplest control method. The other methods are increasingly more complex but enable higher capacities.

6.4.4.5 Vehicle

The baseline vehicle considered for the Airport People Mover is the Low Capacity Transit System (LCTS).

For airport application, three seats per module or six seats per vehicle are removed, and replaced by luggage racks. Four variations were developed to provide a range of capacities. Table 6 contains the configurations considered; their size, passenger capacity and mass per meter. Configuration A was selected for this example. The capacity of the system is a function of both the vehicle capacity and the control philosophy. Chart 3.3 contains the headways and capacities for configuration A. Assuming the station clear control method, the initial requirement of 1,000 pphpd can be achieved with a 2 car train and the future requirement of 2800 pphpd can be achieved with a 3 car train.

Configuration	Comment	L x W(m)	Design Pax**	Pax/m	m^1(kg/m)
LCTS	Original	7.65 x 2.00	12 + 16 = 28	3.7	859
A	Seats Removed	7.65 x 2.00	6 + 16 = 22	2.9	859
B-1	2 x 0.9 m longer	9.45 x 2.00	6 + 30 = 36	3.8	983
B-2	2 x 1.5 m longer	10.65 x 2.00	6 + 38 = 44	4.1	1,031
C	longer and wider	10.65 x 2.50	8 + 48 = 56	5.3	1,322

** Design passengers are based on a standing load of 4 passengers/m whereas crush capacity is normally based on 6 to 8 passengers/m^2 and included in m^1.

Table 6: People Mover Vehicle Configurations

Configuration	Design Pax	l		1 Car Train H	1 Car Train CAP	4 Car Train H	4 Car Train CAP
A	22	7.65	STN CLR	82.99	954	86.91	3,645
			STN ARR	64.08	1,236	64.08	4,944
	(5 sec. buffer)		STN CLR+	49.82	1,590	52.72	6,009
			STN ARR+				

Note: Cruise speed = 12 ms^{-1}; acceleration = .1g and dwell time = 15 s

H = headway in seconds

CAP = capacity in passengers per hour per direction

Table 7: System Capacity

6.4.4.6 Guideway

The track for this example is elevated. In other applications a combination of elevated, at grade and underground track may be required. The minimum radius curve will be 20 meters. Based on earlier work, the guideway will be equipped with a 220 V single phase AC power rail with the ground return provided through the running rails. This will be used to power the on-board HVAC, lighting and safety systems.

6.4.4.7 Tracks and Switches

The track for this system will have a standard gauge of 1435 mm using 60 lb/yd. rails directly fastened to the guideway. Special trackwork consisting of turnouts, crossovers and expansion joints will be standard rail transit type selected based on the speed of operation and environmental loads.

6.4.4.8 Propulsion and Control

The system utilizes 2 kN LIMs spaced at approximately one reaction rail length. With two LIMs on, the thrust will be virtually continuous. In the cruise region where the speed precision is adequately met by the "natural" thrust speed characteristics of the LIM, solid state switches may be used.

The LIM spacing will be closer in the acceleration zones. In the acceleration/braking region active variable frequency control will be provided by a single Variable Voltage, Variable Frequency (VVVF) controller per line located at each station.

100% fail safe block protection is required. In the braking region, PMDs will be utilized. In order to provide the fail safe protection, the PMDs will be sized to bring a crush loaded vehicle to a stop. Under normal operating conditions, LIMs will be used to drive the lighter vehicles through the PMDs to the station stop location.

The LIM will be a variant of the Changi Final Production T LIM, Catalog #881.16 6/6:11 1. The voltage will be upgraded to 600 Vdc and turns per coil adjusted to obtain the required thrust. The duty cycle should be appropriate to the service level.

6.4.5 Evaluation Passenger Transport

6.4.5.1 Operating Requirement

The passenger system configured with the UTDC/ALCAN vehicle is deemed to meet all the operating requirements.

6.4.5.2 Automatic Operation

The system is fully automatic, but a high level of system monitoring is appropriate for passenger security. To the extent that the airport environment is typically safer than urban environments, the surveillance level may be reduced.

6.4.5.3 Route Feasibility

This can only be answered on a case by case basis, however the features of the LIT system include:

- smaller guideway or tunnel
- steeper grades
- shorter trains (station)
- smaller curve radii (reduced spiral)
- light-weight trains.

Therefore, the LIT system is generally more adaptable to route constraints than conventional AGT systems.

6.4.5.4 Technical Risk

Elements of the LIT system have undergone various levels of implementation and testing. Safety design in operation has not been fully implemented. Therefore, the system is not risk-free. It should be noted that the fundamentals of system design were premised on transit standards.

6.4.5.5 System Cost

All estimates to date have indicated that the LIT system will be less expensive than conventional systems for the capacity range below 5,000 pphpd and possibly up to 10,000 pphpd in certain circumstances.

6.4.5.6 Alternative System Comparison

The typical conventional AGT system is generally not suited to the low capacity end of the airport market because:

i) high system cost due to

- guideway
- control system
- vehicle cost

i) service level must be low because of large vehicle size

Therefore typical installations are limited to i) systems where capacity requirements are high or ii) shuttle systems where a large vehicle is an asset, and control is simplified, or iii) where prestige or necessity dictate an AGT system.

6.4.5.7 Mission Viability

The need for inter-facility passenger transit is well established. However conventional AGT systems cannot meet the lower capacity market because of system cost.

6.4.6 Conclusions

The LCTS LIT system in airport configuration appears to meet all the requirements associated with low capacity applications such as Newark and PIA (approximately 3000 pphpd). Higher capacities and/or larger station spacing may require:

i) more cars per train
ii) use of the control strategies developed in this study, or
iii) somewhat larger cars.

The seating and door configuration of the vehicle is certainly well suited to airport applications.

7.0 COMBINED SYSTEMS REVIEW

7.1 BACKGROUND AND PURPOSE

Four transportation systems for airports are being proposed and evaluated in this project:

- Interterminal Baggage Transport (BTS)
- Intraterminal Baggage Transport (LP)
- Airport Freight Transport
- Airport People Moving (LCTS)

A two day meeting was held to examine how the airport systems proposed could be combined, or subsystems shared so as to minimize intrusion and cost.

The purpose of this section is to:

- document the proposed methods of combining the systems,
- outline the analysis and evaluation of the ideas
- and summarize the recommendations

developed during the meeting.

7.2 METHODOLOGY

The task of examining how to combine systems or share subsystems was performed using a meeting format. This approach enabled specialists in

- vehicle design,
- guideway and track,
- propulsion,
- power supply and distribution,
- control,
- and systems

to generate ideas and analyze and evaluate them as a group.

The following meeting agenda was used.

- Discussion of System requirements
- Review of Proposed Systems
- Brainstorm

- o Track, guideway, propulsion, power distribution
- o Analysis of Ideas
- o Evaluation of Ideas
- o Other Ideas
- o Filling in the Blanks
- o Recommendation and Back-up Documentation

7.3 DESCRIPTION OF COMBINED SYSTEMS

Five general methods of combining the airport systems were generated. The methods are:

- o CS1 (Combined System 1): Common Track for Vehicles
- o CS2: BTS/LP Vehicles Carried Onboard Freight Vehicles
- o CS3: BTS/LP Track Enclosed Within Guideway Beam for LCTS/Freight
- o CS4: Dual Gauge Track
- o CS5: Double Track; BTS/LP Covered

These combined systems will be described in the following sections.

7.3.1 CS1: Common Track For Vehicles

7.3.1.1 Rail

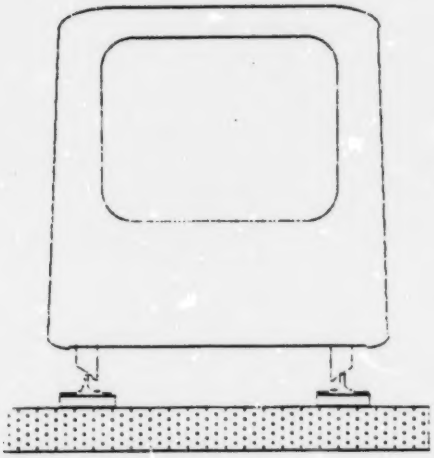
Figure 22 illustrates the system which would combine flanged vehicle systems. In this configuration, the rail and guideway is shared between systems which run on the same gauge. In addition to sharing the rail and guideway, portions of the propulsion, power supply and distribution, and control system could be common. These possibilities will be addressed in Section 7.4.1.

Since the freight vehicle design is based on the LCTS chassis, it would be feasible to run both the LCTS and the freight vehicle on the same track.

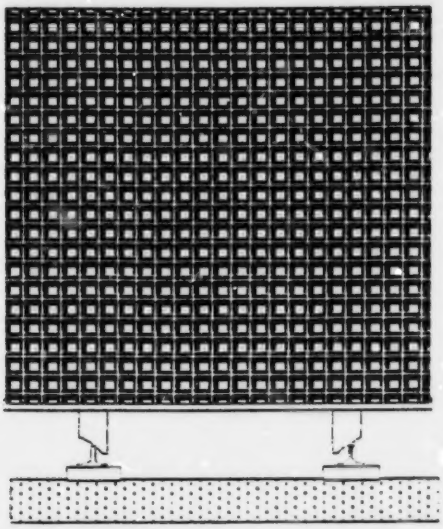
Baggage could be integrated into the same system using two methods:

1. The baggage which is loaded in standard airport containers could be carried on the freight vehicle. Figure 23 shows the most common containers in use for airport baggage.

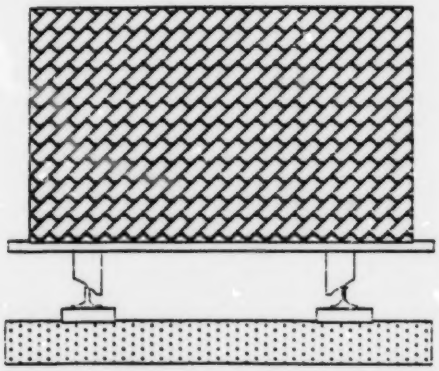
2. The BTS could be redesigned to have steel flanged wheels at standard gauge (1435 mm).



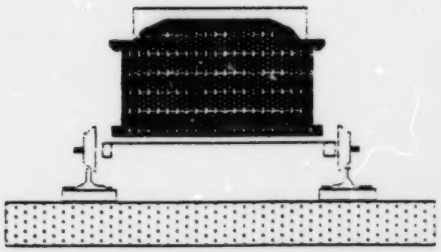
a) People Mover



b) Freight



c) Containerized Baggage

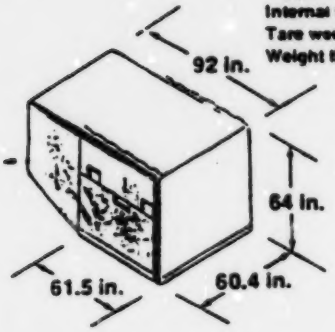


d) Flanged BTS

Figure 22 CS1: Common Track for Flanged Vehicles

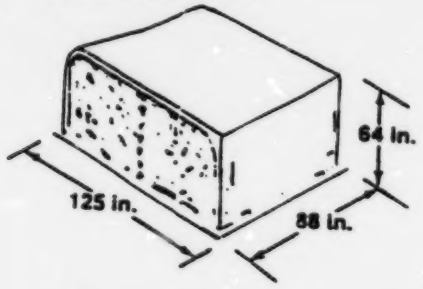
a. wide body: most common

Type: LD-1 Container
Internal volume: 159 to 173 cu ft
Tare weight: 209 to 375 lb
Weight limitations: 3,500 lb

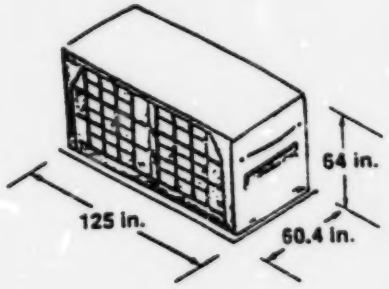


b. wide body: occasional *

Type: LD-9 Structural Container
Internal volume: 329 to 381 cu ft
Tare weight: 485 to 720 lb
Weight limitations: 10,200 lb



Type: LD-11 Structural Container
Internal volume: 246 to 254 cu ft
Tare weight: 410 to 630 lb
Weight limitations: 5,680 to 7,000 lb



* similar containers are occasionally used which have the snout dimension reduced to a minumum of 72 in.

c. 767: most common

Type: LD-2 Container
Internal volume: 120 cu ft
*Tare weight: 152 to 165 lb
Weight limitations: 2,700 lb

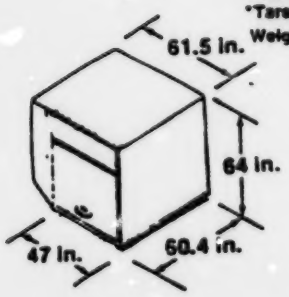


Figure 23: Standard Airport Baggage Containers

7.3.1.2 I-Beam

The BTS was designed to operate on 6" I-beams with a gauge of 1000 mm while the LP was designed to operate on 4" I-beams with a gauge of 750 mm. These could be modified to be standard so the BTS and LP could share portions of track.

7.3.2 CS2: BTS/LP Vehicles Carried Onboard Freight Vehicles

The baggage vehicles, the BTS and the LP, could be transported in sections of the system onboard freight vehicles. Figure 24 illustrates the concept. As in CS1, the people mover and the freight vehicle could utilize the same track.

7.3.3 CS3: BTS/LP Track Enclosed Within Guideway Beam For LCTS/Freight

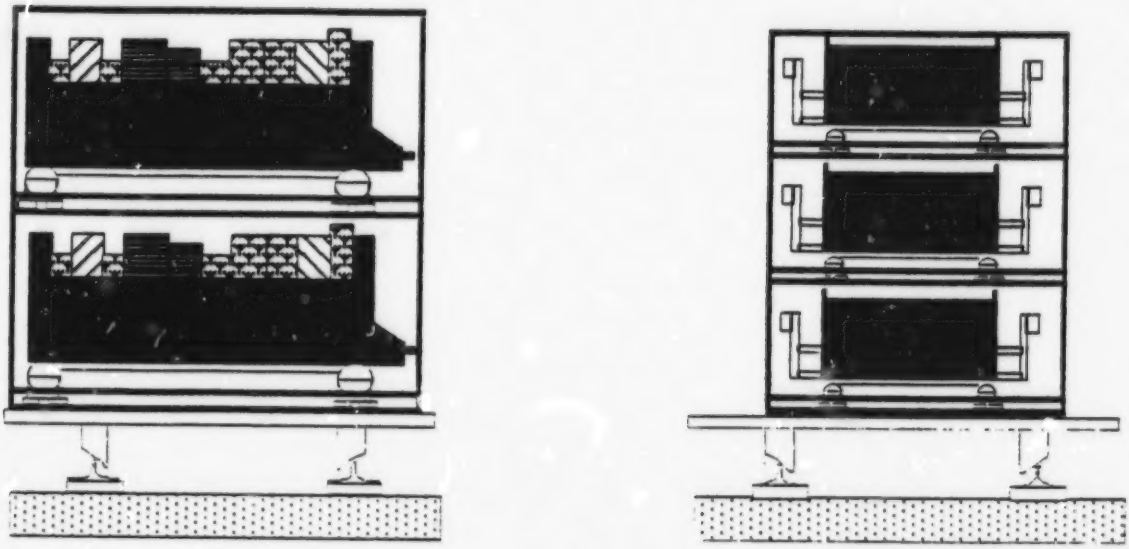
In elevated sections, the guideway for the LCTS and/or freight vehicle could be designed to provide sufficient space within the hollow section for the BTS or the LP system. See Figure 25 for illustrations.

7.3.4 CS4: Dual Gauge Track

The potential exists to install two gauges of track on the same lane of guideway. This is illustrated in Figure 26. The LCTS and freight vehicles could operate on the outer set of rails (1435 mm gauge). Either the BTS (1000 mm gauge) or the LP (750 mm gauge) vehicles could operate on the inner set of I-beams. Both the BTS and the LP vehicles could use the inner beams if their gauges were made compatible.

7.3.5 CS5: Double Track; BTS/LP Covered

The guideway could be shared by two sets of track; one for the LCTS/freight vehicles and the second for the BTS/LP vehicles. This concept is illustrated in Figure 27. With this arrangement, only the section of the guideway used by the baggage handlers would be covered for weather protection. The covered section could serve as an emergency walkway for the passengers of the people mover.



a) BTS; 6 per platform
(2 levels * 3/level)

b) LP: 12 per platform
(3 levels * 4/level)

Figure 24 CS2: BTS/LP Vehicles Carried Onboard Freight Vehicles

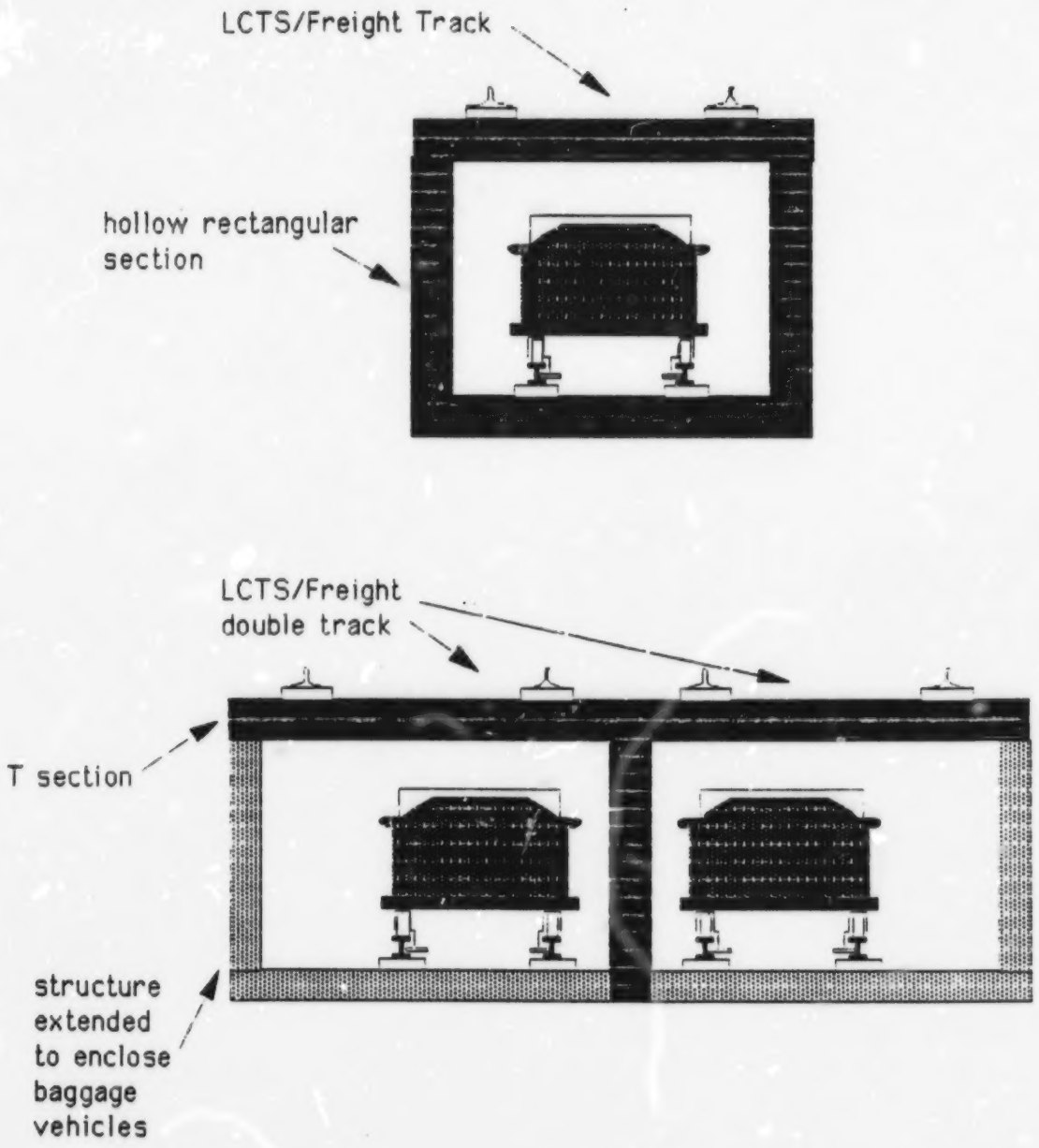
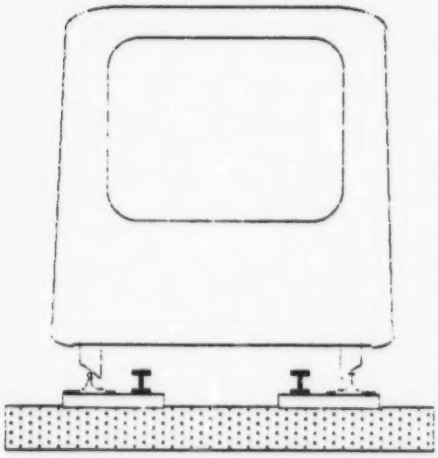
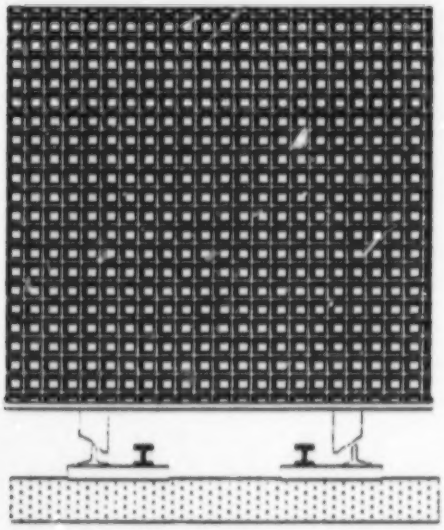


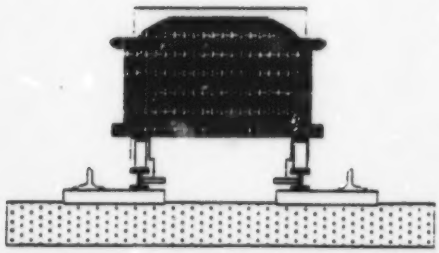
Figure 25 CS3: BTS/LP Track Enclosed Within Guideway Beam for LCTS/Freight



a) People Mover



b) Freight



c) BTS

note: the LP vehicle could operate on the inner beams if the gauge was made consistent with the BTS

Figure 26 CS4: Dual Guage Track

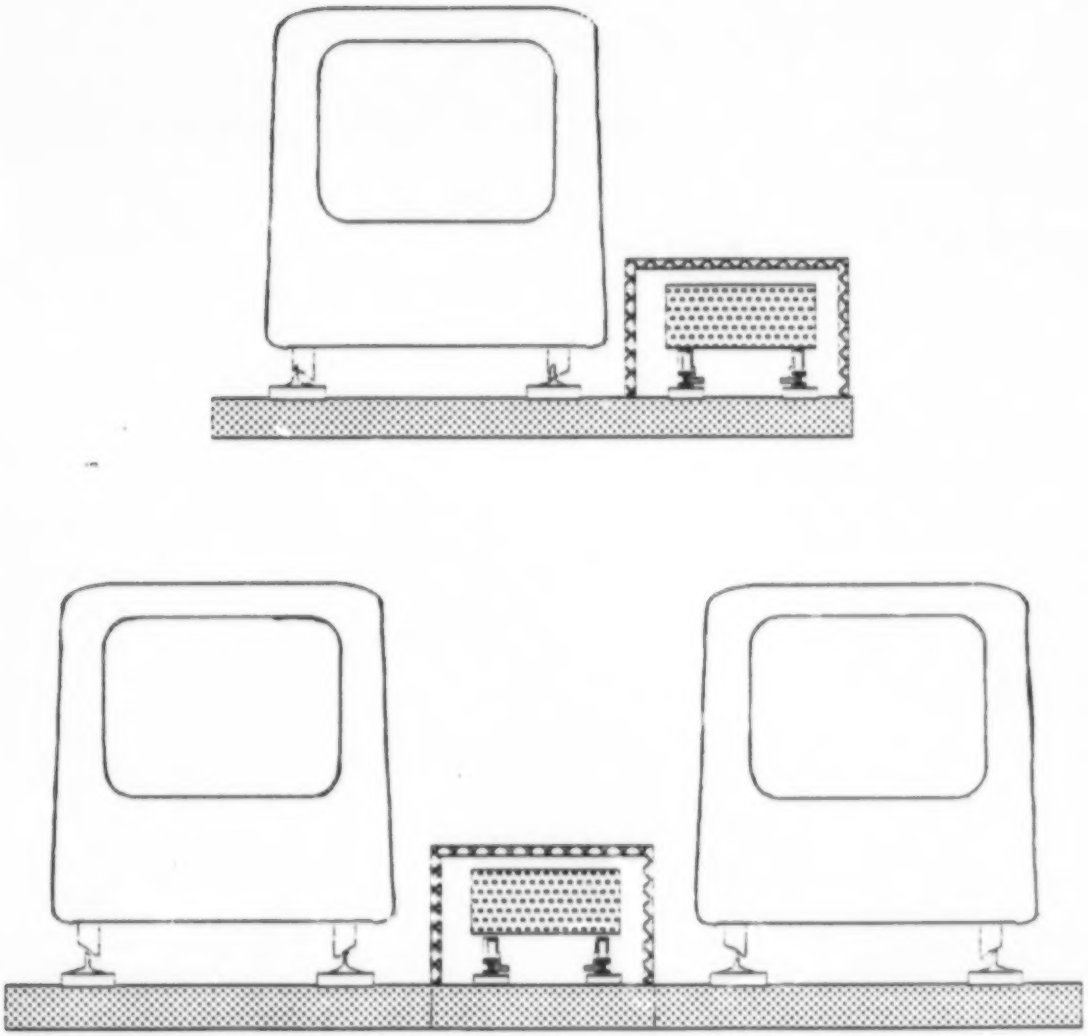


Figure 27 CS5: Double Track; BTS/LP Covered

7.4.0 Discussion of Combined Systems

The implications of combining the airport transportation systems using the five proposed concepts will be discussed in the following sections. Table 8 contains reference vehicle characteristics for the individual systems.

	Gross Mass kg	No. Axles	Length m	Wheels Type	Wheels Diam. in.	Track	Max. Pay Load kg	Max Train	Max Speed ms^{-1}	Min Horiz. R m	Lateral Accel.	Control	Dominant LIM	Long Forces N	Max Grade	Operation
Baggage LP	94	2	1.60	Urethane	4"	Steel I-beam	34	solid	7	1.2	1 g	Bumper	500 N	500	45°	inside
Baggage BTS	400	2	2.44	Urethane	8"	Steel I-beam	170	1 + queue	14	3	1 g	CAS	2 kN	2600	30°	inside
Freight	16,260	4	7.65	Steel	15"	Light Rail	13,636	1	7	20		CAS	6 kN	6000	8%	outside
Passenger A	6575	4	7.65	Steel	11"	Light Rail	2,700	4 +	14	20		Fixed B.	2 kN	7500	8%	outside

Table 8: Vehicle Characteristics for Baggage Freight and Passenger Vehicles

7.4.1 CS1: Common Track for Flanged Vehicles

7.4.1.1 LCTS/Freight

The guideway for a shared system would be sized for the vehicle with the highest load. Table 8 shows the crush masses for the vehicles. In the case of a shared LCTS/freight line, the guideway would be sized for the freight vehicle.

Lightweight (60 lb/yd) continuously welded rail would be used. The LCTS and the freight vehicle (which is based on the LCTS chassis) operate on standard 1435 mm gauge.

Passenger ride and safety requirements will necessitate:

- o continuous propulsion (maximum LIM spacing will be equal to the reaction rail length), and
- o fixed block control.

Three options of operating freight vehicles on the same track while maintaining the passenger requirements were identified. They were:

1. Operate the two vehicle types at their previously identified nominal velocities; passenger vehicles at 12 m/s and freight at 6 m/s. Considering a typical LCTS LIM arrangement, 3 LIMs per vehicle length would be used in the acceleration region. This would result in accelerations of 1 m/s^2 for the passenger vehicle and .4 m/s^2 for the freight vehicle (both at gross mass). The distances required to accelerate from a stop to the operating velocities would be 72 m for the passenger vehicle to accelerate to 12 m/s and 45 m for the freight vehicle to accelerate to 6 m/s. (The freight vehicle could reach 7.6 m/s over a 72 m acceleration zone.) The typical LCTS cruise propulsion arrangement of one LIM per vehicle length would provide sufficient thrust to maintain the speed of the freight vehicle.

   The advantage of this option is that the freight vehicle could operate on the same track as the LCTS without increasing the number of LIMs (or likewise, the number of PMDs or brakes). The disadvantage is that the slower speed of the freight vehicles will increase the headway and decrease the capacity for a given control method.

Note that the capacity could be increased by changing control methods. For example, the control method could be upgraded from station clear to station arrive. Also it would be possible in certain situations to have the slower vehicles "make up time" over the trip by by-passing passenger stations, thereby eliminating the stopping time and the extra time to decelerate and accelerate.

2. Operate the two vehicle types at the higher of the two nominal velocities. The advantage of this option is that the capacity is maintained. The disadvantage is that more LIMs, brakes and PMDs and their controllers will have to be installed to accelerate and decelerate the heavier freight vehicle.

3. Operate the two vehicle types at the higher of the two nominal velocities while avoiding extra propulsion costs by reducing the gross mass per unit length of the freight vehicle. This could be achieved by loading two containers or pallets on the freight vehicle if the combined mass is less than a specified mass. For heavier pallets, only one would be loaded per vehicle. This method would be most effective if a reasonably large percentage of the pallets were less than half the mass of the crush case. Another method would be to increase the reaction rail length by attaching a light "locomotive" unit with a reaction rail.

Assuming the PDS (Power Distribution and Supply) configuration for all LIT systems will be similar to the Changi BTS, i.e.;

- o primary distribution: power supply to terminal areas or station areas or areas where similar power can be utilized (power before conversion).

- o secondary distribution: power supply to individual LIT system power/control elements (e.g., VVVF, LVCM's, SSS's, etc.). This level of power distribution system is configured consistent with the LIT system control blocks.

virtually all PDS can be a common system since the same propulsion equipment and control blocks are used for the various vehicles.

7.4.1.2 LCTS/Freight/Flanged BTS

In order to operate the BTS vehicle on the same track as the LCTS and freight, the urethane running wheels and guidance system would have to be replaced with flanged steel wheels. Figure 28 shows a

possible wheel arrangement. The steering method is similar to the original BTS. The running wheel and guidance wheel assembly is replaced with two 6" cylindrical wheels with flanges. Each set pivots about a point longitudinally centred between the two wheels. Positive guidance is maintained through curves and switches through the tie rod. The tie rod aligns the wheel assembly that does not have flange contact based on the position of the wheel assembly that does have flange contact. Ackerman geometry is utilized to give perfect steering on tangent track and on a specified curve (3 m for the original BTS). Compared to the urethane running wheels and guidance system, this wheel design has two disadvantages;

1. If the angle of attack of the flanged wheel becomes too high during curving, the wheels may climb over the rail. Testing will have to be done to ensure that the curving behaviour is good. If adequate curving behaviour cannot be achieved, the curving radius will have to be increased.

2. The noise will be greater.

The BTS vehicle is not suitable for operation on ice or snow covered rails as the lightweight vehicle is not efficient at breaking up ice. Therefore, the flanged BTS vehicle would require weather protection in most environments. Alternatively, this scenario can be handled by operational measures.

Note that the selection of standard gauge for the LCTS vehicle was required to prevent roll over due to high winds. If the system was totally enclosed and protected from the weather it would be feasible to narrow the gauge to 1000 mm.

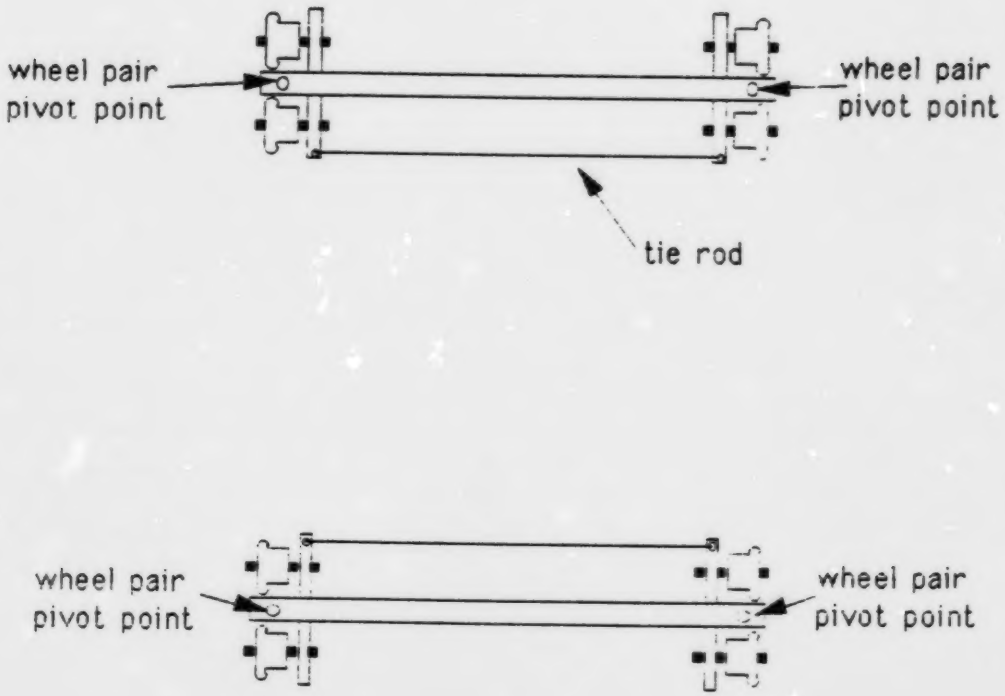


Figure 28: Flanged BTS Wheel Arrangement

In order to efficiently integrate the BTS vehicles into a system with freight and passenger vehicles the BTS vehicles would have to be combined into trains. Therefore, a suitable method of running vehicles as trains would have to be developed.

Similar profile track will have to be installed in dedicated BTS areas. The wider gauge and decreased curving ability will increase the degree of intrusion inside the airport.

7.4.2 CS2: BTS/LP Vehicles Carried Onboard Freight Vehicles

CS2 is very similar to CS1 with the exception that instead of trying to integrate the BTS vehicles into the combined system, the baggage vehicles (BTS or LP) are carried onboard freight vehicles. The guideway, propulsion, control and PSD discussions in Section 7.4.1.1 are also valid for CS2.

Six BTS vehicles could be carried per platform by extending the length 16". Twelve LP vehicles could be carried per platform.

If the baggage station is on the same main track as the other stations, a prerequisite for integrating piggyback vehicles successfully into the system is a time efficient loading and unloading operation. The operations are complicated by the multiple layer configuration. A rack fabricated with track for each vehicle is a viable method of "containerizing" the vehicles for transport. The tracks could be blocked to secure the vehicles during the trip. The rack could be preloaded at the wayside then transferred to a platform as one unit.

Alternatively, the vehicles could be loaded in position onto a holding rack. Racks would also be installed on freight platforms. When the freight vehicle arrives at the station, the racks would be aligned and the baggage vehicles could be quickly rolled onto the onboard rack. Similar methods could be utilized for unloading.

A third approach would be to have the baggage station off the mainline in which case the loading time would not be as critical.

7.4.3 CS3: BTS/LP Track Enclosed Within Guideway Beam For LCTS/Freight

By modifying the LCTS/Freight guideway, the BTS or LP could run inside the guideway beam. Although the guideway cost would be higher than for the conventional LCTS/Freight guideway, the cost would be significantly less than two separate guideways.

Obviously, the BTS/LP systems would require separate track and propulsion from the LCTS/Freight systems running on top of the guideway. However, the primary LIT power distribution could be common. Both the LCTS/Freight propulsion control blocks and the BTS/LP propulsion control blocks could be fed, before power conversion, from a single distribution panel located in or near stations or terminal areas. The secondary LIT power distribution cannot be common.

This configuration has inherent weather protection for the baggage systems as well as security which is of vital concern in an airport environment. The combined system CS3 could have aesthetic drawbacks.

7.4.4 CS4: Dual Gauge Track

In CS4, with two gauges of track installed on the same lane of guideway, the guideway, propulsion and PSD would be shared.

In order to maintain reasonable headways, the baggage vehicles operating on the inner beams would have to be entrained.

As mentioned in the discussion of CS1, the small baggage vehicles (BTS and LP) cannot operate in snow and ice. Therefore, weather protection would be required in most environments.

7.4.5 CS5: Double Track; BTS/LP Covered

The baggage system, BTS or LP, could be integrated into the LCTS/Freight system by adding an additional lane on the guideway. With this arrangement, the cost of providing weather protection for the baggage system would be less than if the entire guideway was being covered. As well, the covered baggage handling system could serve as an emergency walkway for the passengers of the people mover.

In this arrangement the guideway would be shared as well as the primary LIT power distribution. Individual tracks, propulsion, controls and secondary distribution would be required for the LCTS/Freight and BTS/LP systems.

7.5.0 Discussion of Other Ideas Generated

Over the course of the meeting, a number of other ideas were generated and discussed. They are documented in the following subsections.

7.5.1 Utilization of Linear Synchronous Motors

LSMs (Linear Synchronous Motors) have the following characteristics:

- The primary is configured in the same manner as the LIM (Linear Induction Motor) primary,
- The secondary consists of a number of poles with the same pole pitch as the primary. This can be achieved with permanent magnets or through powered windings,
- The typical thrust characteristic plotted against velocity is shown in Figure 29 and is a spike at synchronous speed. Therefore, as long as the vehicle is moving at synchronous speed, the LSM will provide thrust to maintain that velocity. The thrust capability of the LSM has to be sufficient for all required operations of the motor. If the maximum thrust is exceeded, the motor loses synchronism and its thrust capabilities are reduced significantly,
- The power factor and the efficiency of the LSM is higher than the LIM, therefore, smaller power cabling and less power factor correction equipment is required,
- The LSM can be efficiently operated at larger airgaps, and
- The LSM generates smaller normal forces.

LSMs could be utilized in continuous propulsion systems (primaries installed less than 1 reaction rail apart). Open loop control could be used which would result in less control cabling. No speed feedback would be required. The vehicle velocity (which is the synchronous velocity) would be adjusted by changing the supply frequency.

A hybrid secondary which would include conductive end sections would perform as a LIM when in contact with the primary. This allows the vehicle to obtain thrust even if the motor gets out of

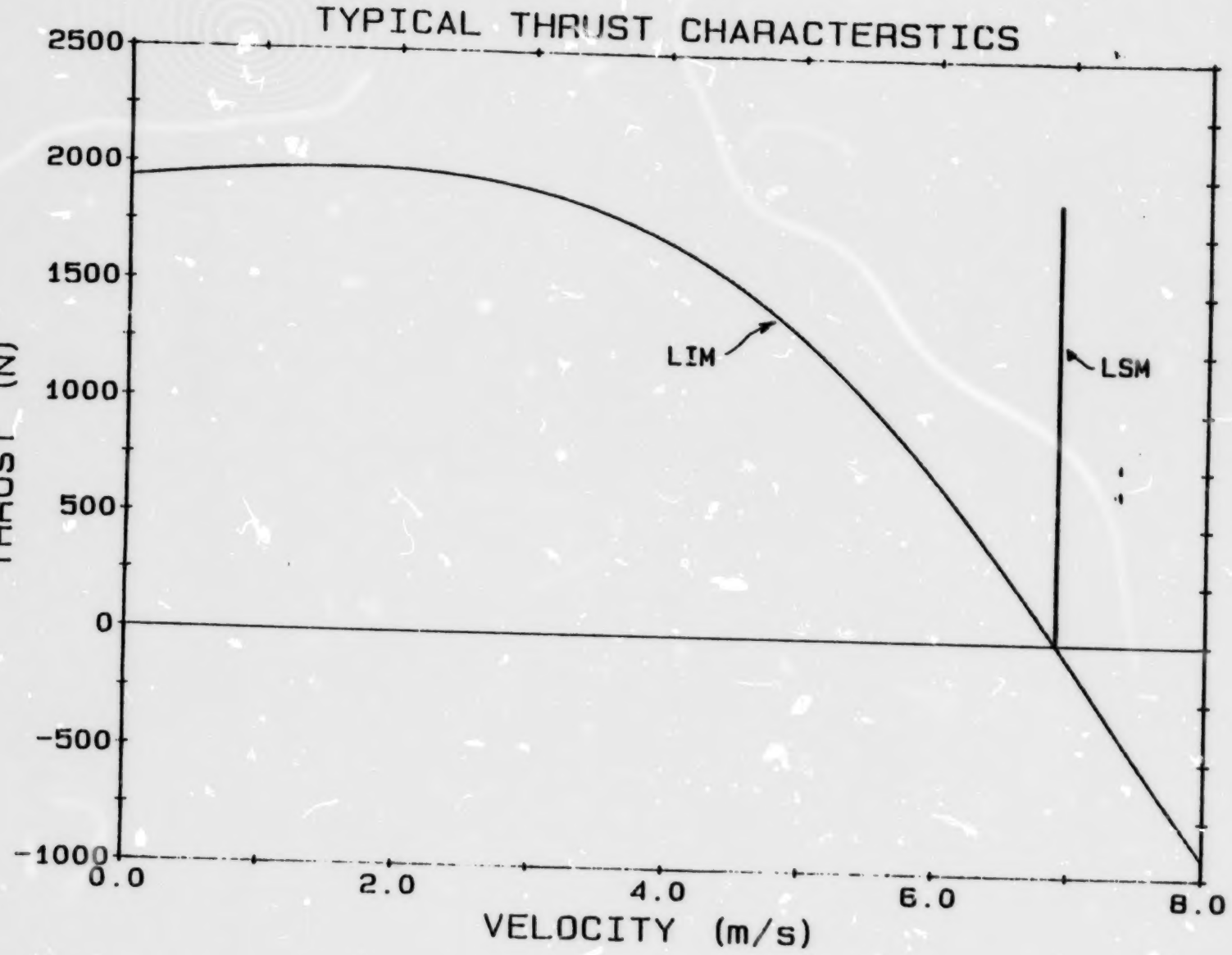


Figure 29: LSM and LIM Thrust Characteristics

synchronism. Once the speed gets close to synchronous speed, the motor will "pull in" the secondary to synchronous speed. The LIM thrust characteristics (again see Figure 5.1) would adjust the vehicle's speed close to the synchronous velocity. This would be a useful characteristic to avoid stalling, especially during vehicle start-up.

Note that permanent magnets are relatively expensive and they attract debris from along the system.

7.5.2 Utilization of Double Sided LIMs

Due to the reduced lateral motion of the BTS/LP baggage vehicles which utilize a wheel guidance system, the use of double sided LIMs becomes possible. See Figure 30 for an illustration. The double sided LIM has the following advantages:

- o Vehicle mass is reduced because no backiron is required in the secondary; just conductive material. As well, the cost of the reaction rail is reduced.

- o The vertical orientation of the reaction rail results in

  - an improved cooling configuration,

  - less critical vertical clearance and tolerances,

  - the ability to mount the reaction rail on the sprung vehicle (due to the less critical vertical clearance),

  - maintained thrust in vertical curves (entry and exit from grades),

  - enabling the reaction rail to also act as the brake rail (again reducing mass and cost), and

  - improved cooling ability.

7.5.3 Integrated LIM, Switch and Sensor

The LIM, solid state switch and sensor could be integrated into a package. The package could be relatively compact and would be easy to install.

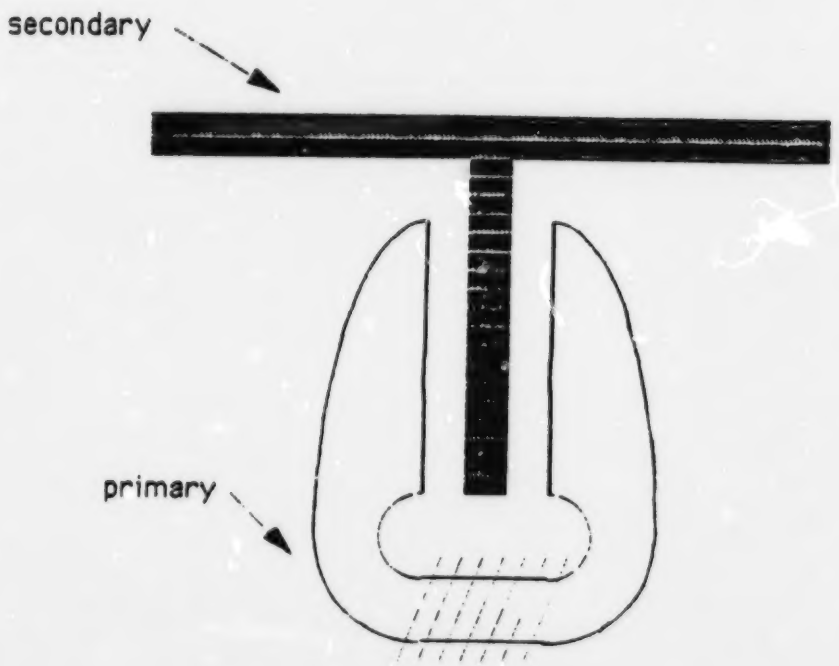


Figure 30: Double Sided LIM

7.5.4 Automatic Loading and Unloading

In several of the individual and combined systems proposed for airport applications, the loading and unloading operations were not specifically addressed. Automatic loading and unloading is generally preferred over manual loading and unloading. In detailed designs, the loading and unloading operations will be considered fully.

7.5.5 Personal Rapid Transit

PRT (Personal Rapid Transit) systems have been too expensive in the past to compete successfully with more conventional forms of public transportation. With the advances in controls and communication, it is felt that the feasibility is increasing for PRT systems.

7.5.6 Automated Baggage Handling

The task of totally automating baggage handling is especially difficult, due to the wide range of sizes, shapes and material characteristics of the baggage. This variation could be eliminated by introducing a "personal" container designed to hold the maximum size of bag. The baggage would be placed in the containers at check-in and would be carried in them for the entire trip. The loading of bags into aircraft containers could then be automated relatively easily. The "container", because it is reusable and retained in the airline system, could be permanently identified, perhaps magnetically. This would enable relatively easy identification and removal of a bag in the event of a "no-show". This would solve a major security problem.

7.5.7 Hybrid LIM In-Track - LIM Onboard System

A hybrid LIM-in-track - LIM onboard system could take advantage of the benefits of both systems. The onboard LIMs would propel the vehicles through the cruise region where the thrust requirements are lower. LIMs would be installed in the track on grades, and in acceleration and deceleration zones.

7.5.8 Off Line Stations for Multi-Use System

By servicing the stations with off-line track the mainline can be utilized more effectively in some arrangements. The potential for time savings is greater in combined systems where the stations for the different vehicle types are in different locations.

7.5.9 Potential For Savings Due to System Similarities

There is a potential for savings to the airport in utilizing a number of these system types (even if they are not combined) due to the similarities between systems. For example, the control room could be common. The systems could have a common maintenance staff, common maintenance procedures and inventory. Advantages due to the common hardware and technology could be maximized through planning during the detailed design of these systems.

7.6.0 Overall Conclusions and Recommendations

The overall conclusion of the meeting was that the combined systems proposed were technically feasible and that they all had cost saving potential. Table 9 summarizes preliminary cost estimates The estimated costs of the combined systems range from approximately 60 to 70% of the separate system costs. Depending on the particular requirements of the airport, any of these proposed combination methods may prove to be optimum.

Due to the substantial cost savings, it is recommended that the concept of combining systems be investigated when the potential exists. The individual systems should be designed with emphasis on commonality where practical.

Combined System #	Description	Systems Combined				Cost (% of separate system cost)
		Passenger	Freight	BTS	LP	
CS1	Common track for vehicles	*	*			70.6
		*	*	*		68.7
CS2	BTS/LP vehicles carried onboard Freight vehicles	*	*	*	*	58.9
CS3	BTS/LP track enclosed within guideway beam for LCTS/Freight	*	*	*	*	69.0
CS4	Dual gauge track	*	*	*	*	64.9
CS5	Double track; BTS/LP covered					69.0

Note: Costs include guideway, track, stations, vehicles, propulsion, PS&D, controls and communication, MSF and support equipment and weather protection where required.

Table 9: Summary of Hardware Costs for Combined Systems

8.0 CONCLUSIONS

The first major conclusion of this study is that LIT system products have been identified for each of the four airport application areas:

- o baggage - interterminal;
- o baggage - intraterminal;
- o air cargo; and
- o passenger.

The second major conclusion is that approaches have been identified which combine systems and effect significant capital and operating cost savings compared with independent systems.

For each system, a typical route and service was established, the system defined to the major hardware selection level, and evaluated. The results of the evaluation were positive, particularly the technical feasibility of meeting the operational requirement, as defined earlier in the study.

The evaluation did identify the particular areas of concern and opportunities with respect to each system, and in further work, these areas must be addressed.

Interterminal Baggage

- o site specific total system cost
- o system cost reduction opportunities

Intraterminal Baggage

- o client interfaces
- o site specific operational options
- o specific technical issues

Air Cargo

- o site specific applications cost/benefit
- o overall mission
- o transfer operations

Passenger

- o site specific application cost/benefit
- o safety implications for system design and operation.

9.0 RECOMMENDATIONS

LIT systems may be the effective transportation means by which airport design operations can be carried out more efficiently. The potential to combine systems may provide the economic lever by which these systems will become attractive to typical airport management.

Therefore, it is recommended that a site specific application study which simultaneously addresses specific system questions and which quantifies the benefits of combined systems, be carried out.

APPENDIX - LIST OF WORKING DOCUMENTS

The tasks of this work were reported as a matter of course, as part of the UTDC Engineering documentation system. There is not a precise one-to-one correspondence between task number and report: eg., Task 2 "literature review" bibliography is contained in report 603-004.

TR 808 603 001	Airport People Mover System Operating Requirements
TR 808 603 002	Freight Handling System Operating Requirements
TR 808 603 003	Baggage Handling System Operating Requirements for Interterminal and Intraterminal Movements
TR 808 603 004	Report on Industry Trends and Key Transportation Issues
TR 808 604 001	Operations Options
TR 808 606 001	Low Profile Baggage Handler: Hardware Identification - Mechanical
TR 808 606 002	"Catalogue" of LIMs, PMDs and Controllers
TR 808 606 003	People Mover Hardware Identification - Mechanical
TR 808 606 004	Freight Hardware Identification - Mechanical
TR 808 606 005	Hardware Identification - LIM
TR 808 606 006	System Descriptions - Example Configurations
TN 808 606 007	Hardware Identification - Guideways
TN 808 606 008	Hardware Identification - Power Distribution
TN 808 607 001	Evaluation of Airport LIT Systems
TN 808 608 001	Combined Systems
TR 808 810 001	Application of LIM-in-Track Technology at Airports

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